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Hawke's Bay Regional Council Earthquake Hazard Analysis Program: Stage III - Evaluation of Ground Shaking Amplification Potential

Volume 2: Appendices

by

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MODIFIED MERCALLI EARTHQUAKE INTENSITY SCALE
NZ 1996 VERSION

HAWKE'S BAY REGIONAL COUNCIL
EARTHQUAKE HAZARD ANALYSIS PROGRAM
STAGE III

[Source: Dowrick, D.J., 1996: The Modified Mercalli Earthquake Intensity Scale - Revisions Arising from Recent Studies of New Zealand Earthquakes. Bulletin of the New Zealand National Society for Earthquake Engineering, 29(2):92-106]

MODIFIED MERCALLI INTENSITY (MM)
NZ 1996 version

MM 1

People

Not felt except by a very few people under exceptionally favourable circumstances.

MM 2

People

Felt by persons at rest, on upper floors or favourably placed.

MM 3

People

Felt indoors; hanging objects may swing, vibration similar to passing of light trucks, duration may be estimated, may not be recognised as an earthquake.

MM 4

People

Generally noticed indoors but not outside. Light sleepers may be awakened. Vibration may be likened to the passing of heavy traffic or to the jolt of a heavy object falling or striking the building.

Fittings

Doors and windows rattle. Glassware and crockery rattle. Liquids in open vessels may be slightly disturbed. Standing motorcars may rock.

Structures

Walls and frame of buildings, and partitions and suspended ceilings in commercial buildings, may be heard to creak.

MM 5

People

Generally felt outside, and by almost everyone indoors. Most sleepers awakened. A few people alarmed.

Fittings

Small unstable objects are displaced or upset. Some glassware and crockery may be broken. Hanging pictures knock against the wall. Open doors may swing. Cupboard doors secured by magnetic catches may open. Pendulum clocks stop, start or change rate (H*).

Structures

Some windows Type I* cracked. A few earthenware toilet fixtures cracked (H).

MM 6

People

Felt by all. People and animals alarmed. Many run outside.* Difficulty experienced in walking steadily.

Fittings

Objects fall from shelves. Pictures fall from walls (H*). Some furniture moved on smooth floors, some unsecured free-standing fireplaces moved. Glassware and crockery broken. Very unstable furniture overturned. Small church and school bells ring (H*). Appliances move on bench or table tops. Filing cabinets or "easy glide" drawers may open (or shut).

Structures

Slight damage to Buildings Type I*. Some stucco or cement plaster falls. Windows Type I* broken. Damage to a few weak domestic chimneys, some may fall.

Environment

Trees and bushes shake, or are heard to rustle. Loose material may be dislodged from sloping ground, e.g. existing slides, talus slopes, shingle slides.

MM 7

People

General alarm. Difficulty experienced in standing. Noticed by motorcar drivers who may stop.

Fittings

Large bells ring. Furniture moves on smooth floors, may move on carpeted floors. Substantial damage to fragile* contents of buildings.

Structures

Un-reinforced stone and brick walls cracked. Buildings Type I* cracked some with minor masonry falls. A few instances of damage to Buildings Type II*. Unbraced parapets, unbraced brick gables and architectural ornaments fall. Roofing tiles, especially ridge tiles may be dislodged. Many un-reinforced domestic chimneys damaged, often falling from the roof-line. Water tanks Type I* burst. A few instances of damage to brick veneers and plaster or cement-based linings. Unrestrained water cylinders (Water Tanks Type II*) may move and leak. Some windows Type II* cracked. Suspended ceilings damaged.

Environment

Water made turbid by stirred up mud. Small slides such as falls of sand and gravel banks, and small rock-falls from steep slopes and cuttings. Instances of settlement of unconsolidated or wet, or weak soils. Some fine cracks appear in sloping ground. A few instances of liquefaction (i.e. small water and sand ejections).

MM 8

People

Alarm may approach panic. Steering of motorcars greatly affected.

Structures

Building Type I, heavily damaged, some collapse*. Buildings Type II damaged, some with partial collapse*. Buildings Type III damaged in some cases. A few instances of damage to Structures Type IV*. Monuments and pre-1976 elevated tanks and factory stacks twisted or brought down. Some pre-1965 infill masonry panels damaged. A few post-1980 brick veneers damaged. Decayed timber piles of houses damaged. Houses not secured to foundations may move. Most un-reinforced domestic chimneys damaged, some below roof-line, many brought down.

Environment

Cracks appear on steep slopes and in wet ground. Small to moderate slides in roadside cuttings and unsupported excavations. Small water and sand ejections and localised lateral spreading adjacent to streams, canals, lakes, etc.

MM 9

Structures

Many Buildings Type I destroyed*. Buildings Type II heavily damaged, some collapse*. Buildings Type III damaged, some with partial collapse*. Structures Type IV damaged in some cases, some with flexible frames seriously damaged. Damage or permanent distortion to some Structures Type V*. Houses not secured to foundations shifted off. Brick veneers fall and expose frames.

Environment

Cracking of ground conspicuous. Landsliding general on steep slopes. Liquefaction effects intensified and more widespread, with large lateral spreading and flow sliding adjacent to streams, canals, lakes, etc.

MM 10

Structures

Most buildings Type I destroyed*. Many buildings Type II destroyed*. Buildings Type III# heavily damaged, some collapse*. Structures Type IV# damaged, some with partial collapse*. Structures Type V# moderately damaged, but few partial collapses. A few instances of damage to Structures Type VI. Some well built* timber buildings moderately damaged (excluding damage from falling chimneys).

Environment

Landsliding very widespread in susceptible terrain, with very large rock masses displaced on steep slopes. Landslide dams may be formed. Liquefaction effects widespread and severe.

MM 11

Structures

Most buildings Type II destroyed*. Many buildings Type III# destroyed*. Structures Type IV# heavily damaged, some collapse*. Structures Type V# damaged, some with partial collapse. Structures Type VI suffer minor damage, a few moderately damaged.

MM 12

Structures

Most buildings Type III# destroyed. Many Structures Type IV# destroyed. Structures Type V heavily damaged, some with partial collapse. Structures Type VI moderately damaged.

NOTES TO 1996 NZ MM SCALE

Items marked * in the scale are defined below.

Construction Types:

Buildings Type I (Masonry D in the NZ 1966 MM scale)

Buildings with low standard of workmanship, poor mortar, or constructed of weak materials like mud brick or rammed earth. Soft storey structures (e.g. shops) made of masonry, weak reinforced concrete, or composite materials (e.g. some walls timber, some brick) not well tied together. Masonry buildings otherwise conforming to Buildings Types I - III, but also having heavy un-reinforced masonry towers. (Buildings constructed entirely of timber must be of extremely low quality to be Type I).

Buildings Type II (Masonry C in the NZ 1966 MM scale)

Buildings of ordinary workmanship, with mortar of average quality. No extreme weakness, such as inadequate bonding of the corners, but neither designed nor reinforced to resist lateral forces. Such buildings not having heavy un-reinforced masonry towers.

Buildings Type III (Masonry B in the NZ 1966 MM scale)

Reinforced masonry or concrete buildings of good workmanship and with sound mortar, but not formally designed to resist earthquake forces.

Structures Type IV (Masonry A in the NZ 1966 MM scale)

Buildings and bridges designed and built to resist earthquakes to normal use standards, i.e. no special collapse or damage limiting measures taken (mid-1930's to *c.* 1970 for concrete and to *c.* 1980 for other materials).

Structures Type V

Buildings and bridges, designed and built to normal use standards, i.e. no special damage limiting measures taken, other than code requirements, dating from since *c.* 1970 for concrete and *c.* 1980 for other materials.

Structures Type VI

Structures dating from *c.* 1980, with well-defined foundation behaviour, which have been specially designed for minimal damage, e.g. seismically isolated emergency facilities, some structures with dangerous or high contents, or new generation low damage structures.

Windows

Type I - Large display windows, especially shop windows.

Type II - Ordinary sash or casement windows.

Water Tanks

Type I - External, stand mounted, corrugated iron water tanks.

Type II - Domestic hot water cylinders unrestrained except by supply and delivery pipes.

H - (Historical) More likely to be used for historical events.

Other Comments

"Some" or "a few" indicates that the threshold of a particular effect has just been reached at that intensity. "Many run outside" (MM6) variable depending on mass behaviour, or conditioning by occurrence or absence of previous quakes, i.e. may occur at MM5 or not until MM7. "Fragile contents of buildings". Fragile contents include weak, brittle, unstable, unrestrained objects in any kind of building. "Well-built timber buildings" have: wall openings not too large; robust piles or reinforced concrete strip foundations; superstructure tied to foundations.

[#] Buildings Type III-V at MM10 and greater intensities are more likely to exhibit the damage levels indicated for low-rise buildings on soft ground. By inference lesser damage to low-rise buildings on soft ground and high rise buildings on firm or stiff ground may indicate the same intensity. These effects are due to attenuation of short period vibrations and amplification of longer period vibrations in soft soils.

APPENDIX B

GEOLOGICAL DATA

HAWKE'S BAY REGIONAL COUNCIL
EARTHQUAKE HAZARD ANALYSIS PROGRAM
STAGE III

GEOLOGICAL DATA

SUMMARY

This appendix describes the methodology used in the acquisition of the geological data. In general, this involved:

- the creation of maps showing Quaternary geology, (these maps delineate deposits using relative age, depositional environment, and grainsize); and
- the evaluation of the thickness of Quaternary deposits in the Hawke's Bay region.

The geological maps are presented as Figure B-1 covering the Hawke's Bay region (at a scale of 1:250,000), and Figure B-2 covering the Heretaunga Plains (at a scale of 1:50,000), in the map pocket at the back of this volume, and Figures B-3 and B-4 covering the Waipawa- Waipukurau and Wairoa areas respectively (at a scale of 1:50,000) on the following pages.

1.0 INTRODUCTION

Geological mapping of the Hawke's Bay region is a necessary step in the work required to describe the variation in ground shaking amplification potential. Most known cases of amplified ground motion in coastal areas have occurred in geologically young (generally Holocene age) sediments (Youd and Hoose, 1978; Tinsley and others, 1985). Preparation of the geological maps has concentrated on the Quaternary geology of the region. The required input of data has come from a variety of sources. These sources include:

- surface geological and geomorphological data;
- subsurface geological data;
- relative and absolute age data; and
- geotechnical data (Appendix G).

The methodology used in the compilation of the geological data set is described below, including sources. Following on from the methodology a brief explanation of the tectonic and geological setting is presented. This includes a set of geological maps that depict the Quaternary geology.

Figure B-3: Quaternary Geology, Waipukurau - Waipawa area

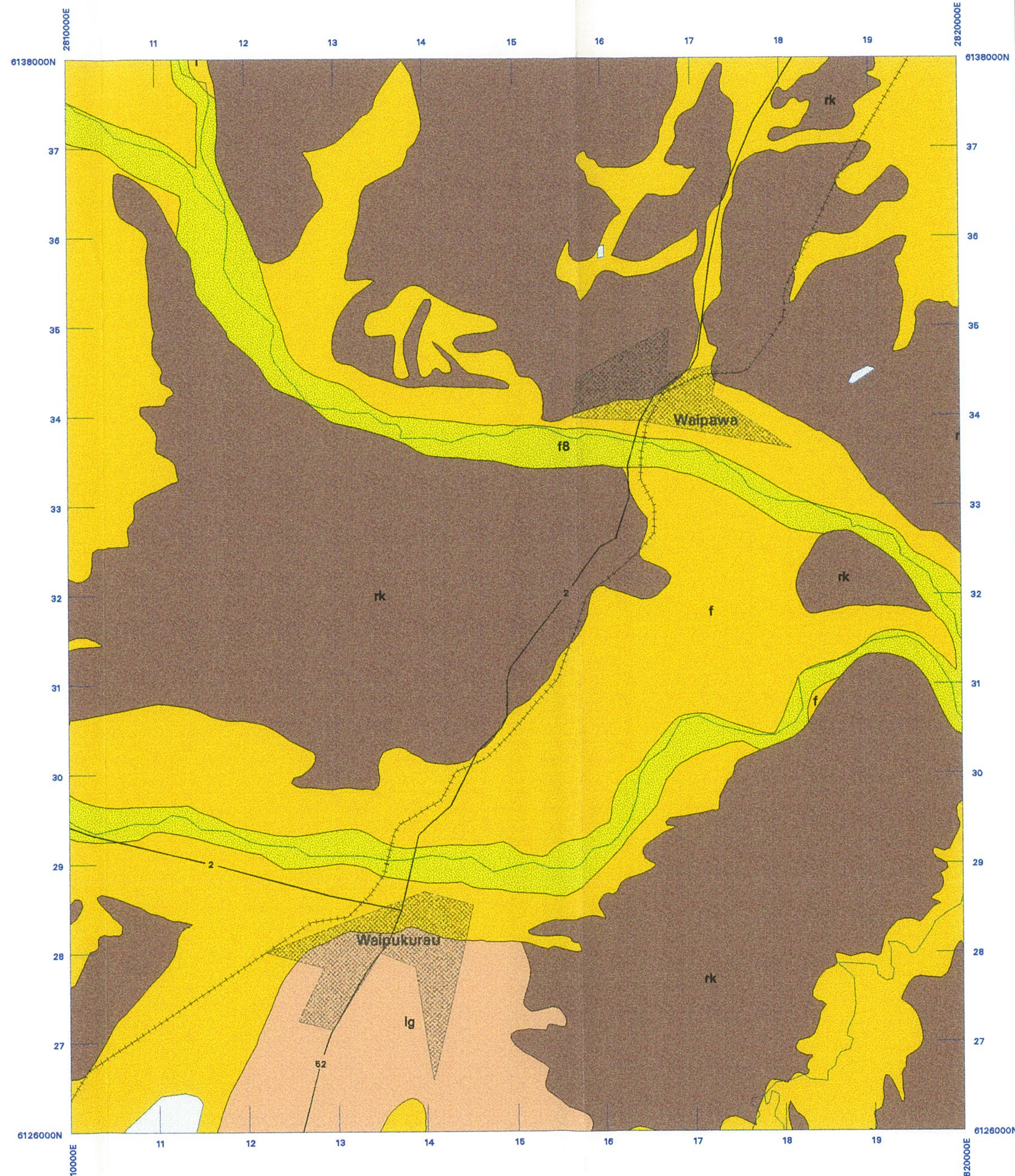
HAWKE'S BAY REGIONAL COUNCIL EARTHQUAKE HAZARD ANALYSIS PROGRAM STAGE III

GEOLOGICAL LEGEND

r	Land reclaimed since 1931; commonly uncontrolled fills over lagoonal areas or previous river channels.
l2	Estuarine and lagoonal deposits of sand, silt, and minor gravel from the pre-1931 Ahuriri Lagoon.
l1	Estuarine and lagoonal deposits of sand, silt, and minor gravel that have been drained or reclaimed since 1850.
b	Beach ridges, beaches and tombolos of gravel and sand.
m	Estuarine and lagoon deposits consisting of silty clay and silty sands with discontinuous gravel lenses. Sand content increases near beaches.
f	Undifferentiated alluvium.
fw	Moderately to coarsely interlayered silt, sandy silt, silty sand and sand deposits (Wairoa River sediments).
f8	Present river channels. Consist of lenticular sands and gravels in the main channels, with interlayered silt deposits.
f7	Former river channels occupied in historical time prior to flood control and the 1931 earthquake. Consist of lenticular sands and gravels in the main channels, with interlayered silt deposits (overbank flood deposits).
f6	Former river channels occupied last century. Consist of lenticular sands and gravels in the main channels, with interlayered silt deposits (overbank flood deposits).
f5	Finely to moderately interlayered silt and fine sand deposits; (overbank flood deposits).
f4	Finely to moderately interlayered silt and sand (overbank flood deposits) including extensive 1,800 year Taupo pumice flood deposits.
f3	Lenticular sands and gravels with interlayered silt and pumice deposits (c. 3,000 to 1,800 year former river deposits).
f2	Lenticular sands and gravels with interlayered silt (c. 6,500 to 3,000 year former river deposits).
f1	Lenticular sands and gravels with interlayered silt (c. 14,000 to 6,500 year former river deposits).
vf	Silty sand and discontinuous fine gravels with clay (valley fill).
lg	Lenticular sands and gravels with interlayered silt (c. > 14,000 years BP [last glaciation]).
rk	Pre-Quaternary geology.

TOPOGRAPHIC REFERENCE

- Urban area
- Road
- Railway
- River
- Water



The geological units shown on this map provide an indication of the likely geological conditions in a given area. Site-specific investigations should be conducted to determine actual soil properties and ground shaking amplification potential. The information will be used by the Hawke's Bay Regional Council at its own risk. The Institute of Geological and Nuclear Sciences Limited, while providing the information in good faith, accepts no responsibility for any loss, damage, injury, or loss in value of any person, property, service or otherwise resulting from earthquake hazards or knowledge of earthquake hazards in the Hawke's Bay Region.

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SCALE 1:50 000

1 0 1 2 3 4 5 6 kilometres

Figure B-4: Quaternary Geology, Wairoa area

HAWKE'S BAY REGIONAL COUNCIL EARTHQUAKE HAZARD ANALYSIS PROGRAM STAGE III

GEOLOGICAL LEGEND

r	Land reclaimed since 1931; commonly uncontrolled fills over lagoonal areas or previous river channels.
l2	Estuarine and lagoonal deposits of sand, silt, and minor gravel from the pre-1931 Ahuriri Lagoon.
l1	Estuarine and lagoonal deposits of sand, silt, and minor gravel that have been drained or reclaimed since 1850.
b	Beach ridges, beaches and tombolos of gravel and sand.
m	Estuarine and lagoon deposits consisting of silty clay and silty sands with discontinuous gravel lenses. Sand content increases near beaches.
f	Undifferentiated alluvium.
fw	Moderately to coarsely interlayered silt, sandy silt, silty sand and sand deposits (Wairoa River sediments).
f8	Present river channels. Consist of lenticular sands and gravels in the main channels, with interlayered silt deposits.
f7	Former river channels occupied in historical time prior to flood control and the 1931 earthquake. Consist of lenticular sands and gravels in the main channels, with interlayered silt deposits (overbank flood deposits).
f6	Former river channels occupied last century. Consist of lenticular sands and gravels in the main channels, with interlayered silt deposits (overbank flood deposits).
f5	Finely to moderately interlayered silt and fine sand deposits; (overbank flood deposits).
f4	Finely to moderately interlayered silt and sand (overbank flood deposits) including extensive 1,800 year Taupo pumice flood deposits.
f3	Lenticular sands and gravels with interlayered silt and pumice deposits (c. 3,000 to 1,800 year former river deposits).
f2	Lenticular sands and gravels with interlayered silt (c. 6,500 to 3,000 year former river deposits).
f1	Lenticular sands and gravels with interlayered silt (c. 14,000 to 6,500 year former river deposits).
vf	Silty sand and discontinuous fine gravels with clay (valley fill).
lg	Lenticular sands and gravels with interlayered silt (c. > 14,000 years BP [last glaciation]).
rk	Pre-Quaternary geology.

TOPOGRAPHIC REFERENCE

- Urban area
- Road
- Railway
- River
- Water

The geological units shown on this map provide an indication of the likely geological conditions in a given area. Site-specific investigations should be conducted to determine actual soil properties and ground shaking amplification potential. The information will be used by the Hawke's Bay Regional Council at its own risk. The Institute of Geological and Nuclear Sciences Limited, while providing the information in good faith, accepts no responsibility for any loss, damage, injury, or loss in value of any person, property, service or otherwise resulting from earthquake hazards or knowledge of earthquake hazards in the Hawke's Bay Region.

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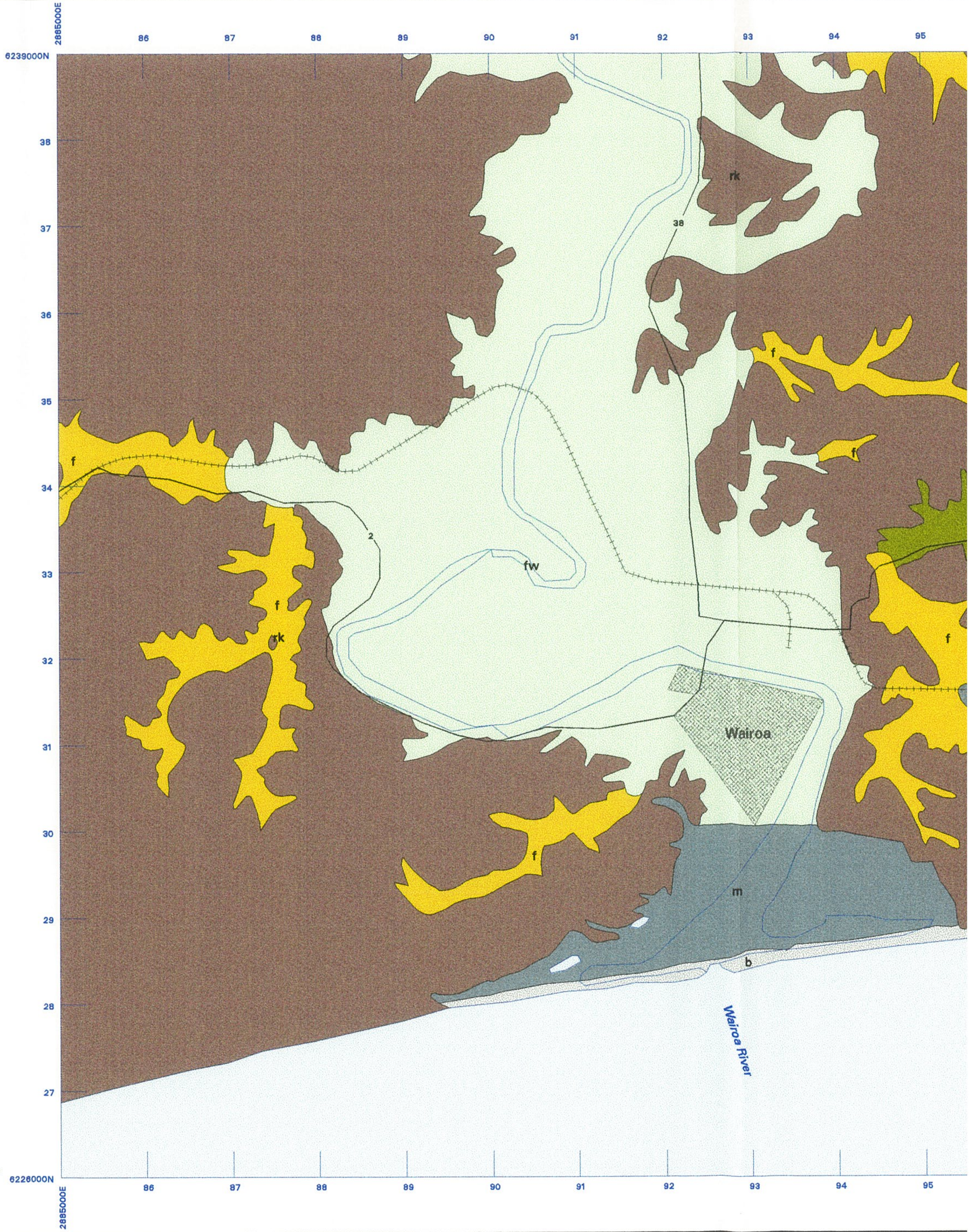
SCALE 1:50 000

1 0 1 2 3 4 5 6 kilometres



2.0 METHODOLOGY

2.1 Quaternary Geology Mapping

The initial task of developing the Quaternary geology maps involved compiling surficial geological and soils data from published and unpublished sources prepared by the former Department of Scientific and Industrial Research (DSIR), the Institute of Geological and Nuclear Sciences, and private consulting companies. Unpublished geological quadrangle maps prepared by IGNS for Hawke's Bay Regional Council's groundwater studies (Brown et al., 1996) differentiate Quaternary sediments including units such as former stream channel deposits, beach deposits, swamp deposits, dune deposits, terraces, fans, and artificial fill. These maps also assign approximate geologic ages or relative ages to the units, and include some information on general deposit thicknesses.

Quaternary deposits were mapped at a scale of 1:250,000 (Figure B-1, map pocket) except around the main urban centres where they were mapped at 1:50,000 (Figures B-2 (map pocket); B-3; and B-4 (following pages)). Units were defined on the basis of age and environment of deposition. Mapping relied on:

(1) evaluation of existing geological, pedological and topographical maps;

(2) stereographic interpretation of aerial photographs; and

(3) field reconnaissance mapping and evaluation.

Topographic map and aerial photographic interpretation techniques were used to delineate landforms, such as stream terraces, marshes, and floodplains. Topographic maps of different vintages were used to assess the changes resulting from urbanization, and major base level changes following the 1931 earthquake to delineate areas of filled, reclaimed ground adjacent to the coastline, and major river systems.

Quaternary deposits and geomorphic surfaces were mapped on the basis of several stratigraphic, geomorphic, and pedologic criteria, including:

(1) topographic position in a sequence of inset deposits or surfaces;

(2) relative degree of surface modification (e.g., erosional dissection, etc.);

(3) relative degree of soil-profile development or other surface weathering phenomena;

(4) superposition of deposits separated by erosional unconformities and/or buried soils;

(5) relative or numerical ages of individual deposits;

(6) physical continuity and lateral correlation with other stratigraphic units; and,

(7) textural or lithologic uniqueness such as inclusion of distinctive volcanic ash, estuarine sediment, silica cementation, or exotic clast lithologies.

Field reconnaissance was completed to examine geomorphic relationships, outcrops, stream-bank exposures, and artificial exposures, concentrating on landforms likely to be underlain by deposits capable of amplifying ground shaking, such as Holocene floodplains, filled land, and lowlands. Field observations are fundamentally important to verify mapping performed through interpretation of aerial photographs, and to obtain information that can not be obtained otherwise, such as sediment density and soil profile development.

2.2 Age Estimation of Quaternary Deposits

Understanding the stratigraphy of the mapped Quaternary deposits and associated landforms is a critical element in establishing the relative age relationships between Quaternary units. This is a critical factor in the assessment of site amplification of ground shaking (Borcherdt, 1994). Over time, sediments become increasingly consolidated and densified, and may develop cementation. Some of the river deposits within the study area develop a silica cementation over a short geologic time period. These "aging" effects make the sediments less susceptible to amplification and liquefaction.

Briefly, the key Quaternary geological units (some of which are further differentiated for this study) are:

(1) Reclaimed land, generally fills over lagoonal areas or previous river channels;

(2) Estuarine and lagoonal deposits;

(3) Beach ridges, beaches and tombolos of gravel and sand;

(4) River alluvium (this unit has been finely subdivided based on age and environment of deposition - see Figure legends);

(5) Last glaciation gravels;

(6) Pre-Quaternary geological units.

Previous studies in the area have established age control on a number of important geological units. These studies include Dravid & Brown (1996), Brown (1993), Brown & Gibbs (1996), Suggate (1985), Kamp (1982, 1990), Beu (1995), Black (1992), Lewis (1973), Kingma (1970, 1971), and Kelsey *et al* (1993).

2.3 Subsurface Geology

The degree of ground shaking amplification is in part dependent on the nature and thickness of geological materials at depth. The nature of the these materials can affect the amplitude (severity) of shaking, modify the frequency of the shaking, e.g. amplifying long period motions, but dampening short period motions, and can increase the duration of the shaking. All of these factors have a significant bearing on the overall performance of buildings during strong earthquake ground shaking. Therefore, information on the subsurface geology of the region was required to assist in assigning geological units to a site response class as is described in the main report.

Subsurface data from exploratory boring logs (e.g. Ota *et al*, 1989), well logs (Dravid & Brown, 1996), seismic CPT soundings (Barker, 1997; see Appendix G) and geophysical surveys were used to assess the distribution and thickness of Quaternary sediments, and establish shear wave velocity profiles for the units. Data sources included primarily the well log data base from HBRC, IGNS files, and logs of borings and soundings from previous studies.

To supplement the existing data, a series of seismic CPT probes were completed specifically for this project. The results of this work are included in Appendix G; the methodology for this technique is described fully in Barker and Stephenson (1991). These probes provide information on the stratigraphy, texture and shear wave velocity profile of a site, which is then used in assigning a geological unit to a site response class.

3.0 GEOLOGICAL AND TECTONIC SETTING

New Zealand lies along the margins of two tectonic plates: the western part of the country lies on the Indian-Australian plate, while the eastern part lies on the Pacific plate (e.g. Walcott, 1978). The boundary between these two plates is characterised by faulting, folding and associated seismological and volcanological activity.

The boundary trends between these two plates through and east of the North Island and involves subduction of the Pacific plate beneath the Australian plate at a rate of *c.* 44 mm/year (e.g. DeMets et al, 1990). The convergence between the two plates in central Hawke's Bay is at an oblique angle with an inclination of about 50° to the coast (e.g. Kamp *et al*, 1992). The Pacific plate starts sinking beneath the Indian-Australian plate at the Hikurangi trough about 200 km east of Napier, and becomes progressively deeper to the west. The down-going plate dips gently (about 6°) immediately west of the trough (Reyners, 1980; Bannister, 1986), but steepens beneath central Hawke's Bay to about 25° (Adams and Ware, 1977). The zone between the trough and the axial ranges of the North Island is a zone of intense deformation and is known variously as the East Coast Fold Belt (Katz, 1974), Axial Tectonic Belt (Walcott, 1978a) and East Coast Deformed Belt (Sporli, 1980). Folding and faulting within the belt is caused by oblique compressional stress generated by the subduction process.

The East Coast Deformed Belt, which comprises the Axial Ranges and is characterised by a set of strike-slip faults in the west (including the Ruahine and Mohaka faults), and a reverse fault zone (including thrust faults) dipping away from the Hikurangi trough (Sporli. 1980).

The present day physiography of coastal Hawke's Bay has evolved through the combined effects of tectonic deformation, erosion and sea-level fluctuation over the last *c.* 1.5 million years. The Heretaunga Plains represents a tectonic depression developed between actively growing folds within the East Coast Deformed Belt (Ravens, 1990; 1991). Beneath the Heretaunga Plains, up to 1 km of Pleistocene (post *c.* 2 million years) gravel, sand and silt overlie the local limestone and sandstone bedrock. Accumulation of more than 240 metres of young (< 250 000 years) sediments within the Heretaunga Plains depression illustrates that crustal deformation is an on-going process.

The Ruataniwha Plains is another depression that is located between a series of west-dipping, NE-trending reverse faults. This basin has also accumulated a thick succession of gravel deposits during the last 1.5 million years.

Since the end of the cold period of the last glaciation (*c.* 18,000 years ago) climatic warming and melting of polar icecaps has caused a sea level rise of about 120 m. Sea level reached its present position *c.* 6,000 years ago, and has remained more or less stable to the present day. Large parts of the area of the present Heretaunga Plains were inundated by this rise in sea level, resulting in the deposition of young fine grained intertidal marine silts. Subsequently, the continuing supply of sediment from the mountain ranges to the west, and regular changes in the course of the Tukituki, Ngaruroro and Tutaekuri rivers have built up the plain above sea level and shifted the coastline eastwards. This has resulted in a complex sequence of river channel and flood plain deposits overlying shallow marine sediments. Flood plain sediments deposited in the last 10,000 years are up to 20 metres thick with a thickness ranging from 0-40 metres for the shallow marine sediments (Dravid and Brown, 1997).

After the most recent large eruption of Taupo *c.* 1,800 years ago, large quantities of Taupo Pumice Alluvium built up rapidly on the Heretaunga Plains. The pumice has been eroded in some places by alluvial processes, but up to 10 m thickness of pumice gravel and sand are found in many parts of the plains. Aggradation of the rivers has continued since the pumice deposition, with a further 5-10 m of alluvial sediment overlying the pumice in parts of the Heretaunga Plains.

The fluvial sediments of the Heretaunga plains (units f2, f3, f4, f5, and f6), are comprised of interfingered layers and lenses of sand, silt and gravel. The lagoonal and estuarine deposits in the vicinity of Napier appear to form a shallow veneer (up to 40 metres) of soft sediments which overlie the interlayered fluvial deposits (up to 20 metres thick) of the Heretaunga plains (Dravid and Brown, 1997). These are in-turn locally overlain by coarse sands and gravels of the beach deposit (up to 20 metres thick) along Marine Parade in Napier (Dravid and Brown, 1997).

At Wairoa sub-surface investigations (Ota *et al*, 1989) show up to 30 metres of recent (post-glacial) fine sands and deposited in an estuarine environment.

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APPENDIX C

HISTORICAL EARTHQUAKE DATA

HAWKE'S BAY REGIONAL COUNCIL
EARTHQUAKE HAZARD ANALYSIS PROGRAM
STAGE III

HISTORICAL EARTHQUAKE DATA

SUMMARY

Analysis of the historical earthquake record throws up some interesting observations.

In the Waipawa-Waipukurau area, MM intensities are generally fairly similar. Although during individual earthquakes there may be minor variations in the MM intensities reported. This occured, for example, during the 1931 Napier earthquake.

The same phenomenon is observed on the Heretaunga Plains with Napier generally experiencing higher shaking intensities than Hastings, although there are exceptions where the difference is the other way round (for details refer to Table 3.1 in Begg *et al*, 1994).

At Wairoa only one event (1904, Cape Turnagain) provided information on variations in intensity with the intensity being one unit higher at Frasertown than at Wairoa.

Generally the historical record shows that some areas (e.g. Napier) experience amplified ground shaking during moderate to strong shaking. Closer analysis of the damage data may enable refinement of this observation. For example, at Napier amplification of ground shaking may occur both because of weak ground and because of topographic enhancement.

1.0 INTRODUCTION

Hawke's Bay has been subjected to strong earthquake shaking on a number occasions since European settlement began in New Zealand in the 1840's. This appendix briefly describes the damage that occurred during earthquakes that generated shaking of MM6 or greater in the main urban centres of Hawke's Bay. Relevant earthquakes include the 1855 Wairarapa earthquake, 1863 Waipawa, 1904 Cape Turnagain, 1931 Napier, and 1932 Wairoa earthquakes. An attempt is made to identify areas that experienced amplified shaking.

2.0 THE EARTHQUAKES

2.1 Wairarapa Earthquake of 23 January 1855

The isoseismal map of Grapes and Downes (1997) (Figure C-1) shows MM 5 at Wairoa, MM 6 in the Heretaunga Plains and MM 7 for the Waipawa-Waipukurau area. The absence of Europeans in the Waipawa-Waipukurau area has prevented an assessment of the damage in this area as there are no known written records. On the Heretaunga Plains a possible fissure, 250-300 mm wide and extending for some considerable distance was reported. Without a more accurate location all that can be said of this fissure is that it probably occurred in comparatively weak sediments. Colenso, who was living near Clive at the time, was shaken, but did not report his chimney being shaken down. At Wairoa where the intensity was MM 5 no ground damage was reported although the duration of shaking was reported as lasting 5 to 7 minutes.

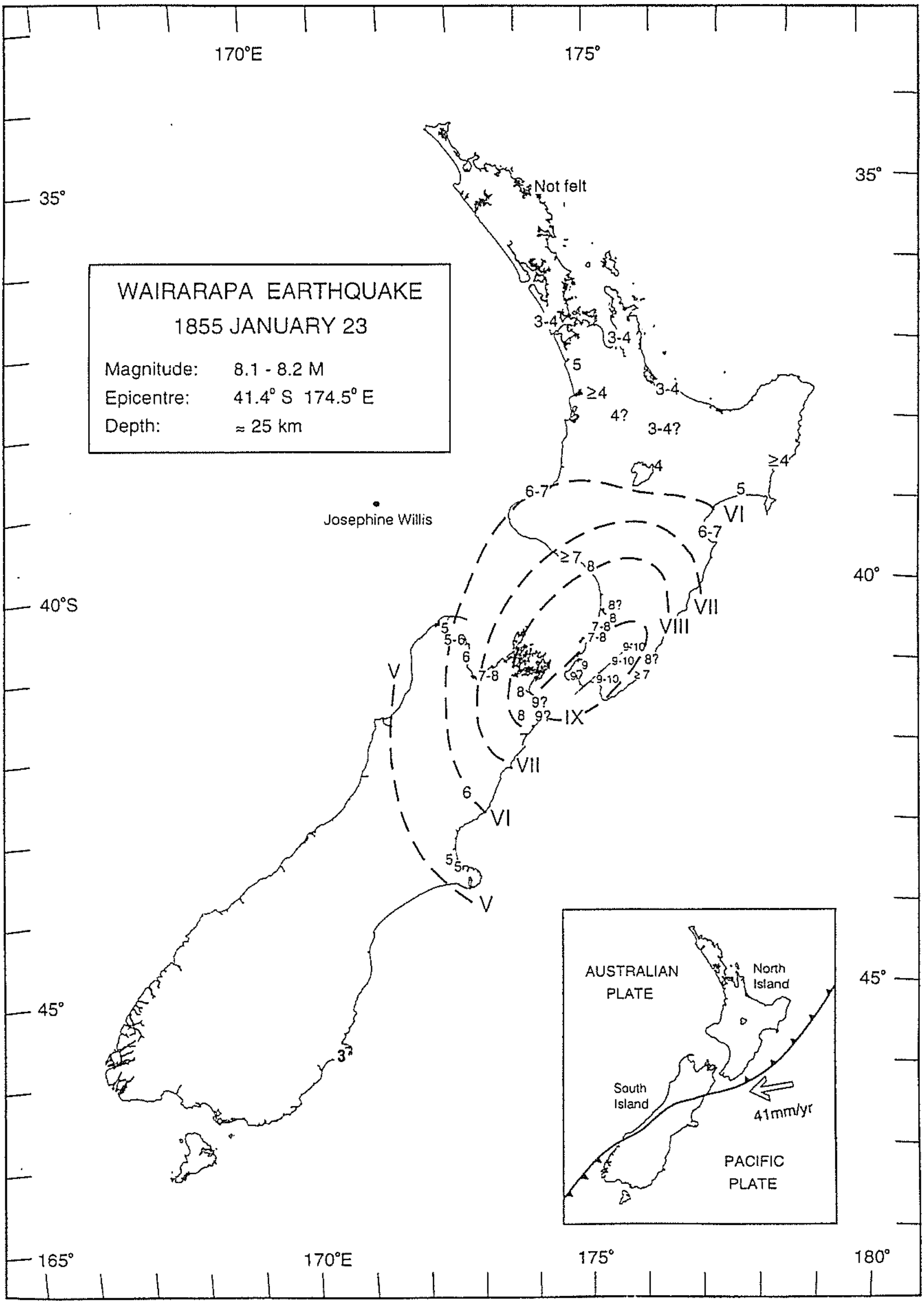

Figure C-1: Modified Mercalli intensities for the Wairarapa earthquake of 23 January, 1855 (from Grapes and Downes, 1997).

2.2 Central Hawke's Bay Earthquake of 23 February 1863

Damage attributed to this earthquake has been obtained from GNS files. At Napier the shaking intensity reached at least MM 7 (and possibly MM 7-8) based on the descriptions of damage. This included a report from the banks of the Piremu (*sic* - Purimu?) Stream (the most likely site for this feature is near Napier) which stated that: "Near the banks of the Piremu Stream 20 holes oozing sand and water were observed". It was also observed at Napier that "the road to the spit exhibits several cracks, but it having been all new ground at a comparatively recent period renders this an unimportant fact". Innumerable chimneys were reported broken. Both the ground damage and the structural damage at Napier are consistent with a shaking intensity of MM 7.

No information specifically referring to Hastings has been sighted. In the Waipukurau-Waipawa area where MM 8-9 has been assigned there were reports of large cracks opening in the alluvium. However, the accounts are somewhat confused and may describe a fault rupture. No reports of damage have been sighted for Wairoa.

2.3 Cape Turnagain Earthquake of 9 August 1904

By the time of the 1904 Cape Turnagain earthquake, Hawke's Bay was much more closely settled and because of this it is possible to identify variations in ground shaking due to the underlying ground conditions on the Heretaunga Plains (Figure C-2).

At Napier a large number of chimneys were brought down, reclaimed land at Whare-O-Maraenui was badly cracked with sand boils, and sand boils were also reported on the left bank of the Tutaekuri River from Taradale to Meanee (Hancox, *et al*, 1997). This damage is consistent with a shaking intensity of MM 7.

However at Hastings, chimneys were only cracked and a few windows were broken. No ground damage was reported from Hastings. The damage at Hastings is consistent with a shaking intensity of MM 6.

At Waipawa chimneys were brought down and sand boils were reported from nearby at Patangata (Hancox *et al*, 1997). This is consistent with a shaking intensity of MM 7. No data on the damage at Waipukurau has been sighted.

At Wairoa a shaking intensity of MM 5 has been assigned for Wairoa itself, while Frasertown a few kilometres further up the valley has been assigned MM 6.

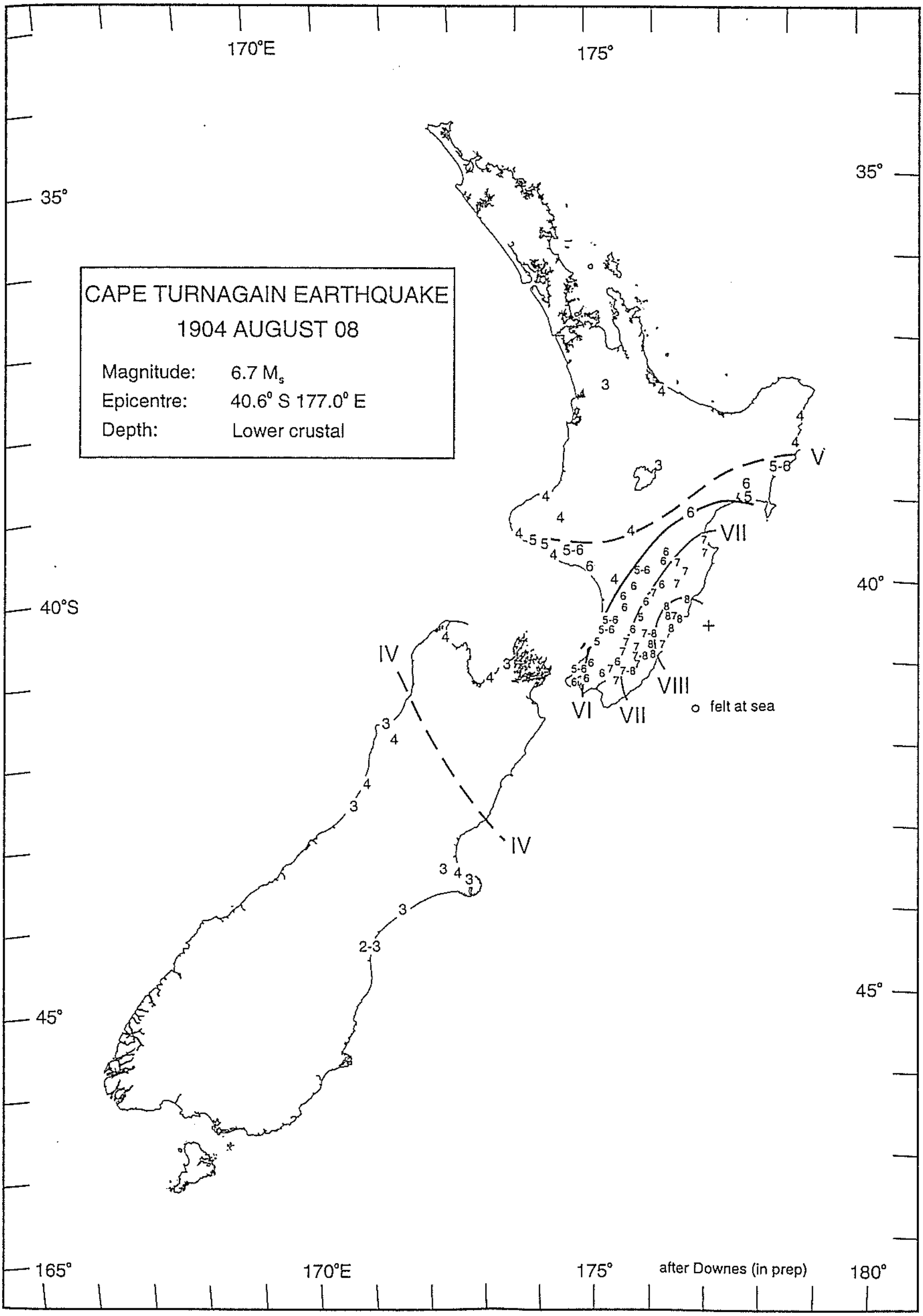

Figure C-2: Modified Mercalli intensities for the Cape Turnagain earthquake of 8 August, 1904 (from Downes, 1995).

2.4 Napier Earthquake of 3 February 1931

The epicentre of the magnitude 7.8 earthquake was located close to Napier and caused MM 10 intensity shaking in the Napier area (Figure C-3). Damage reports from Napier describe ground damage almost exclusively from reclaimed swamp and lagoon areas. Analysis of the distribution of damage from this event (Dowrick, *in prep*) indicates that greatest damage, (i.e. the highest damage ratios) occured on soils that suffered from ground damage (i.e. liquefaction effects). For soils that did not show ground damage, the greatest damage to houses occured on rock sites, the least damage on "soft" soil sites and an intermediate level of damage on "firm" soil sites.

Damage on the plains was in fact less than would have been anticipated given the magnitude and proximity of the event. Though not yet verified, this may have been due to the dampening effects of soft soils at high accelerations and the occurrence of liquefaction, either at the surface or at depth. Butcher (1931) notes that although damage to buildings was greater on Scinde Island, particularly Bluff Hill, the damage to buried services was greater in Napier South where ground fissures were much more evident. This indicates that the soils of Napier South failed in shear (liquefaction-type damage).

At Hastings MM 10 was assigned. No reports of ground damage from Hastings itself have been sighted (Hancox *et al*, 1997). However, structural damage to buildings was consistent with MM 10.

At Waipawa, MM 7 was been assigned, while at Waipukurau MM 8 was assigned. The difference in shaking intensity assigned to these two towns is contrary to Baird (1931) who reported an observer noted "that the intensity round Waipawa-Te Aute region had been worse than any other part south of Napier.

At Wairoa MM 7 was assigned (Downes, 1995).

2.5 Wairoa Earthquake of 16 September 1932

The Wairoa earthquake of 16 September 1932 caused MM 9 (Dowrick, pers. comm.) intensity shaking at Wairoa (Figure C-4). Some fissuring and cracking of the ground was reported in the vicinity of Wairoa (Hancox *et al*, 1997).

At Napier the intensity of shaking reached MM 6-7, while at Hastings it only reached MM 5-6 (Downes, 1995). At Waipawa and Waipukurau the intensity of shaking reached MM 5.

3.0 DISCUSSION

Analysis of the historical earthquake record throws up some interesting observations.

In the Waipawa-Waipukurau area, MM intensities are generally fairly similar. Although during individual earthquakes there may be minor variations in the MM intensities reported. This occured, for example, during the 1931 Napier earthquake.

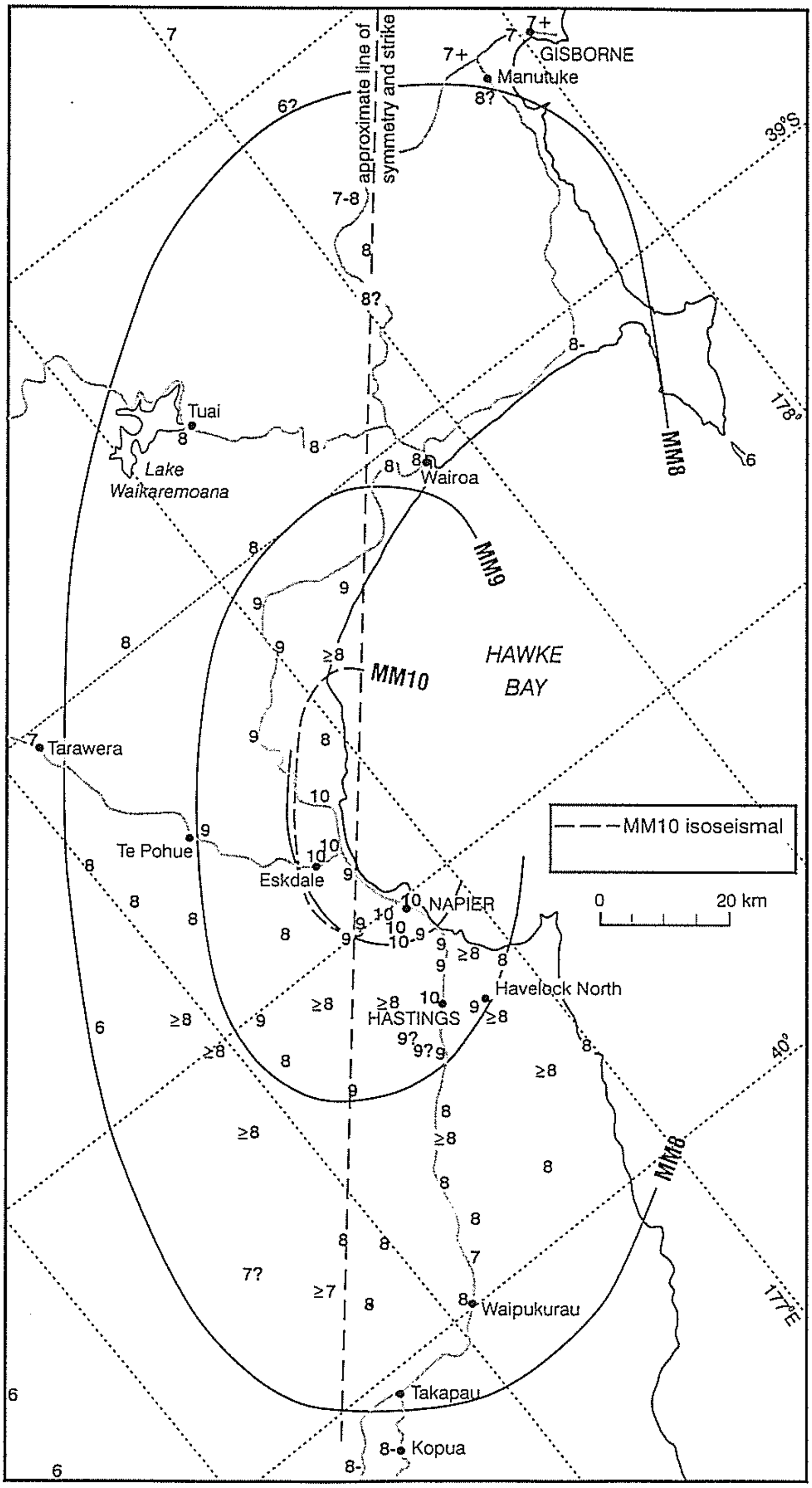

Figure C-3: Modified Mercalli intensities for the Hawke's Bay earthquake of 3 February, 1931 (from Dowrick, *in prep*).

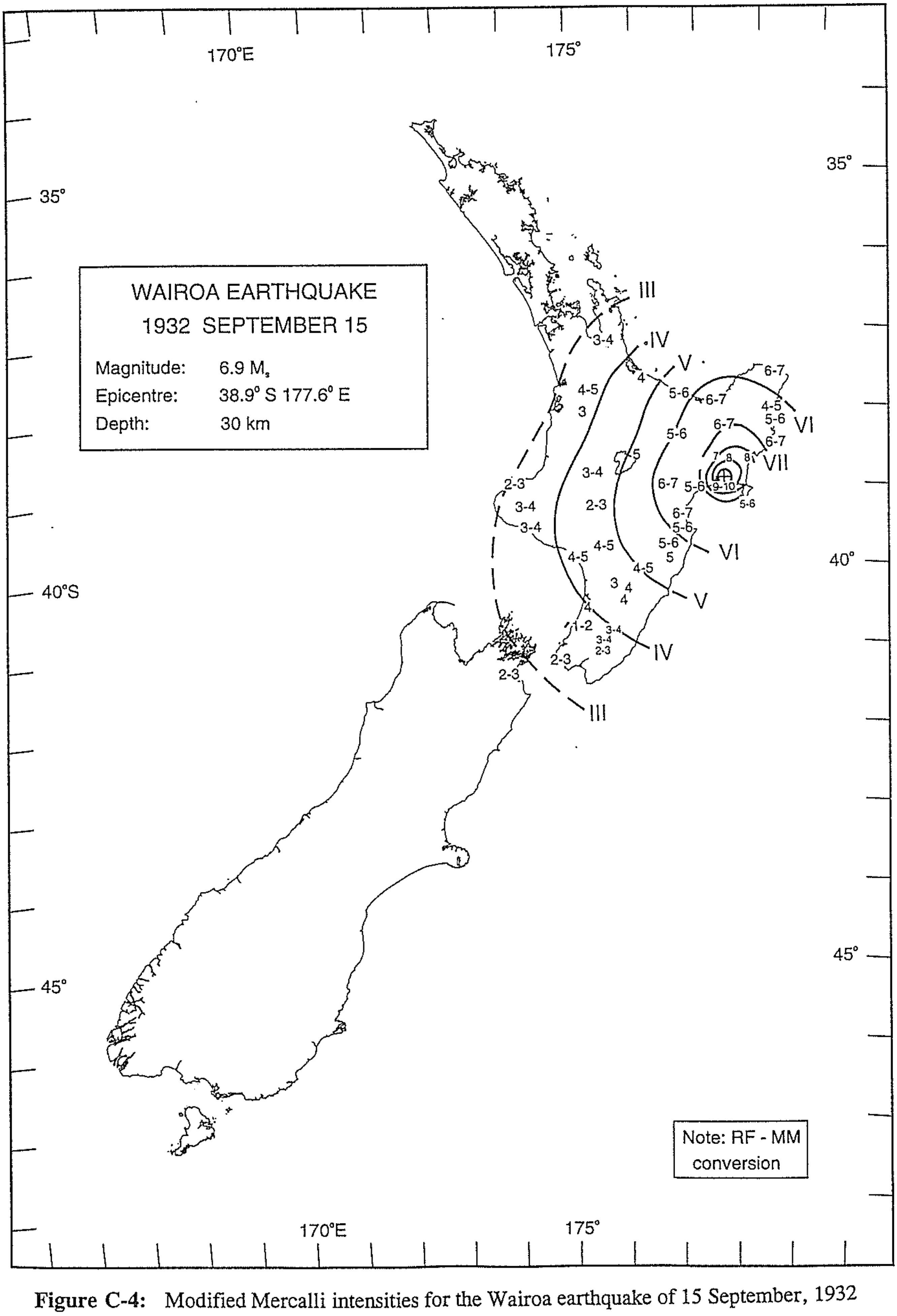

Figure C-4: Modified Mercalli intensities for the Wairoa earthquake of 15 September, 1932 (from Downes, 1995).

The same phenomenon is observed on the Heretaunga Plains with Napier generally experiencing higher shaking intensities than Hastings, although there are exceptions where the difference is the other way round (for details refer to Table 3.1 in Begg *et al*, 1994).

At Wairoa only one event (1904, Cape Turnagain) provided information on variations in intensity with the intensity being one unit higher at Frasertown than at Wairoa.

Generally the historical record shows that some areas (e.g. Napier) experience amplified ground shaking during moderate to strong shaking. Closer analysis of the damage data may enable refinement of this observation. For example, at Napier amplification of ground shaking may occur both because of weak ground and because of topographic enhancement.

4.0 REFERENCES

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APPENDIX D

NAKAMURA ANALYSES

HAWKE'S BAY REGIONAL COUNCIL
EARTHQUAKE HAZARD ANALYSIS PROGRAM
STAGE III

NAKAMURA ANALYSES

SUMMARY

This appendix describes the methodology used in the acquisition of microtremor data and the results of processing the microtremor data using the Nakamura method (Nakamura, 1989). Ambient, or background ground vibrations are recorded on a portable seismograph. This data is then processed using the Nakamura method. This enables the potential resonance at a site to be evaluated.

The value of the Nakamura technique is that data on site response (microtremor data) can be quickly gathered in the field, and analyzed to assess the resonant characteristics of a number of sites. The flexibility of the technique allows it to be used as a screening technique to identify which areas may or may not be susceptible to the amplification of strong ground shaking.

The Nakamura method provides a reasonable estimate of the natural frequency of a resonant site, and a rough estimate of the amplification, provided that the local geology is simple. The Nakamura method will confidently locate highly resonant areas where a widespread uniform soft layer has an abrupt interface with firmer material.

Microtremors were recorded at 31 locations in the Hawke's Bay region. The analysis of microtremor data from the Hawkes Bay region using the Nakamura method has identified some strongly resonant sites. Areas which exhibit resonant behaviour include the former Ahuriri lagoon, coastal areas on the north side of Scinde Island, Havelock North, Flaxmere and Hastings. Areas where no clear indication of resonance is seen include areas of the former Ahuriri lagoon south of Scinde Island. Sites at Waipukurau, Waipawa, Flaxmere, the Napier CBD and Napier Hospital do not amplify ground shaking according to the Nakamura method.

1.0 THE NAKAMURA METHOD

In brief, the Nakamura method (Nakamura, 1989) considers waves trapped in a uniform surface layer. Multiple reflections of these waves between the top and bottom of the layer give rise to resonances. Vertical resonant motion at the surface is due to trapped p-waves, while horizontal resonant motion at the surface is due to trapped s-waves.

P-waves travel much faster than s-waves in recent sediments and they will not be resonantly amplified at the s-wave natural frequency of a layer, so can be taken as a proxy for non-amplified s-waves. It follows that the ratio of the s-wave spectrum to the p-wave spectrum will have a character that shows the natural frequency and amplification factor of the site, and that the ratio of the spectrum of horizontal motion to the spectrum of vertical motion will behave in the same way. This latter ratio has been named the quasi-spectral ratio (sometimes referred to as the Nakamura ratio).

The method has been tested both by field measurements in known situations, and by computer modelling. The outcome of this testing is that for microtremor motions the method gives an accurate value of the dominant period of motion, and a rough estimate of the amplification factor applicable for low to moderate strength seismic input, provided site conditions are simple.

The technique has been applied in several areas around the world. Perhaps the most relevant work is that of Ohmachi et al. (1991), in which the Nakamura method was applied to microtremors recorded in the Marina district of San Francisco, the area which was severely damaged during the 1989 Loma Prieta earthquake. By using the Nakamura technique to analyze microtremors it was possible to show a strong correlation between the highly resonant sites identified using the Nakamura technique and the areas most heavily damaged during the earthquake.

2.0 THE NAKAMURA METHOD IN NEW ZEALAND

Nakamura's method has been applied to a number of sites in New Zealand (Alfredton, Timberlea, Miramar, Porirua and Parkway). Our experience with the applicability of the Nakamura Method agrees with those of other investigators in that, if the site is resonant, the frequency of resonance can be predicted, but that the amount of amplification is difficult to predict. In the case of Alfredton, the microtremor-derived quasi-spectral ratio indicated moderate broad-band amplification; stronger than was seen in recordings of earthquakes.

In the cases of Timberlea and Miramar complex multiple resonances were indicated, and in Parkway (Wainuiomata) moderate resonant amplification was expected, but high amplifications were observed during earthquakes. This was in contrast with the main Wainuiomata valley where the quasi spectral ratio correctly predicted the extremely high amplifications which were observed. It appears that the results from the Wainuiomata main valley were accurate because the site approximates an extended soft layer over rock, whereas the Parkway gully is narrow and depth-varying. In the latter case, the quasi spectral ratio may reflect a very local geometry whereas earthquakes would excite the basin as a whole, resulting in a different resonant character.

Results from Porirua emphasise the care which should be taken when considering quasi-spectral-ratios which are unsupported by other data. On the basis of Nakamura's method by itself, because the quasi-spectral ratio for Porirua was much the same as for Alfredton, the earthquake responses of the two sites could be expected to be similar. However, both these sites have been examined in great detail, and their soil-to-rock spectral ratios in small earthquakes are well known, as are the shear wave velocity profiles below both sites. The Porirua site in fact has much the same small earthquake amplification as Wainuiomata (extremely high amplification), albeit at a different frequency, and the Porirua amplification factor and frequency were both accurately predicted beforehand by Stephenson et al (1990) on the basis of geotechnical measurements.

The technique does appear to have limitations where the stratigraphy of a site lacks a clear interface between the soft and firm layers, especially in the case of a shear wave velocity profile which increases gradually with depth. The microtremors recorded at Alfredton, where there is such a shear wave profile, yield a very broad-band quasi-spectral ratio. This does not mean that amplification is not expected. As energy propagates from the stiffer to the less stiff material the wave amplitude should increase, and such an increase occurs in Alfredton, as shown by the slightly greater amplitudes of motion seen on soil compared with rock during earthquakes. Further work should show whether broad band resonances are associated with velocities steadily increasing with depth.

Another possible limitation to the Nakamura technique is that structures other than basins can be expected to resonate with a natural frequency for horizontal motion which is quite different from the natural frequency for vertical motion. Examples are buildings, ridges and embankments. In such cases, the quasi-spectral ratio can reveal the resonant character of the relevant object, though the identity and extent of the object may not be obvious. Furthermore, such a resonant object could radiate seismic waves, which in turn could have a dominant horizontal component so that the resonant character of a building for instance, could emerge in microtremor records made close to it. This effect, if not recognised, can lead to ambiguous interpretations of the microtremor recordings.

In general, we consider that the Nakamura method provides a reasonable estimate of the natural frequency of a resonant site, and a rough estimate of the amplification, provided that the local geology is simple. We can add, however, that we are confident that the method will locate highly resonant areas where a widespread uniform soft layer has an abrupt interface with firmer material.

3.0 DATA COLLECTION IN THE HAWKE'S BAY REGION

Microtremors (ambient ground vibrations) were recorded at 31 locations in the Hawkes Bay region (Figure D-1 - in map pocket; and Figure D-2 - on following page). The initial survey was carried out by David Baguley and Fred Langford on April 8-10, 1997 (sites N1 to N28a). The second survey was carried out later on during 1997 (sites N29 & N30). The criterion employed for the detailed selection of a site for the first survey was quick and easy vehicular access, as anything else would extend the required 10 minute recording time. The measurement locations were selected on the basis of the geological mapping described in Appendix B (Volume 2), with the intention of assessing the resonance of each significant geological unit, and identifying sites for the more comprehensive weak motion earthquake recording investigation. The second survey was carried out to provide information at specific sites identified by cone penetrometer tests (CPT) and Seismic cone penetrometer tests (SCPT) probing.

Recordings were made for a minimum of ten minutes at each location. In this process, a seismometer (Kinemetrics model L4C-3D) senses the ground velocity along each of three axes, producing voltages which are recorded by an EARSS seismograph (Gledhill, 1991) at a rate of 100 samples per second. The seismometer used has a nominal natural frequency of 1 Hz, and a nominal damping of 67% of critical. Table D-1 shows the assessed amplification and its resonant frequency.

Table D-1: Nakamura test sites and their assessed resonant amplifications. Weak motion study sites and geotechnical investigations sites included for reference. It should be noted that the sites used for the various studies, while often in the same general area, are not necessarily at exactly the same site. This is important when comparing results from the different studies as the local geology can vary a lot laterally.

Site #	Physical description	Grid reference NZMS 260	Resonance	Weak motion study site	CPT and SCPT site #
N1	Northumberland St/Russell St, Waipukurau	2813450 6128550	MAYBE @ 1.2 Hz		
N2	Bridge inside stopbank, Waipukurau	2813750 6128900	NO		
N3	Post Office, Waipawa	2816700 6134150	NO		
N4	Awarua Crescent at Havelock North domain	2843350 6162250	YES @ 0.54 Hz		
N5	St Lukes School, Havelock North	2842800 6163250	YES @ 0.34 Hz	W1	

Figure D-2: Investigation Locations, Waipukurau - Waipawa area

HAWKE'S BAY REGIONAL COUNCIL EARTHQUAKE HAZARD ANALYSIS PROGRAM STAGE III

INVESTIGATION SITES

- Non Resonant Nakamura Site
- Possibly Resonant Nakamura Site
- Resonant Nakamura Site
- Non Resonant Nakamura Site (also Weak Motion Site)
- Possibly Resonant Nakamura Site (also Weak Motion Site)
- Resonant Nakamura Site (also Weak Motion Site)
- Non Resonant Nakamura Site (also Weak Motion Site and SCPT Site)
- Possibly Resonant Nakamura Site (also Weak Motion Site and SCPT Site)
- Resonant Nakamura Site (also Weak Motion Site and SCPT Site)
- Weak Motion Site only
- SCPT Site only

TOPOGRAPHIC REFERENCE

- Urban area
- Road
- Railway
- River
- Water

The presence of a hazard zone on the map does not guarantee the existence of such a hazard, nor does the lack of a hazard on the map preclude the existence of a hazard. Site-specific investigations should be conducted to determine actual soil properties and ground shaking amplification potential. The information will be used by Hawkes Bay Regional Council at its own risk. The Institute of Geological and Nuclear Sciences Limited, while providing the information in good faith, accepts no responsibility for any loss, damage, injury, or loss in value of any person, property, service or otherwise resulting from earthquake hazards or knowledge of earthquake hazards in the Hawkes Bay Region.

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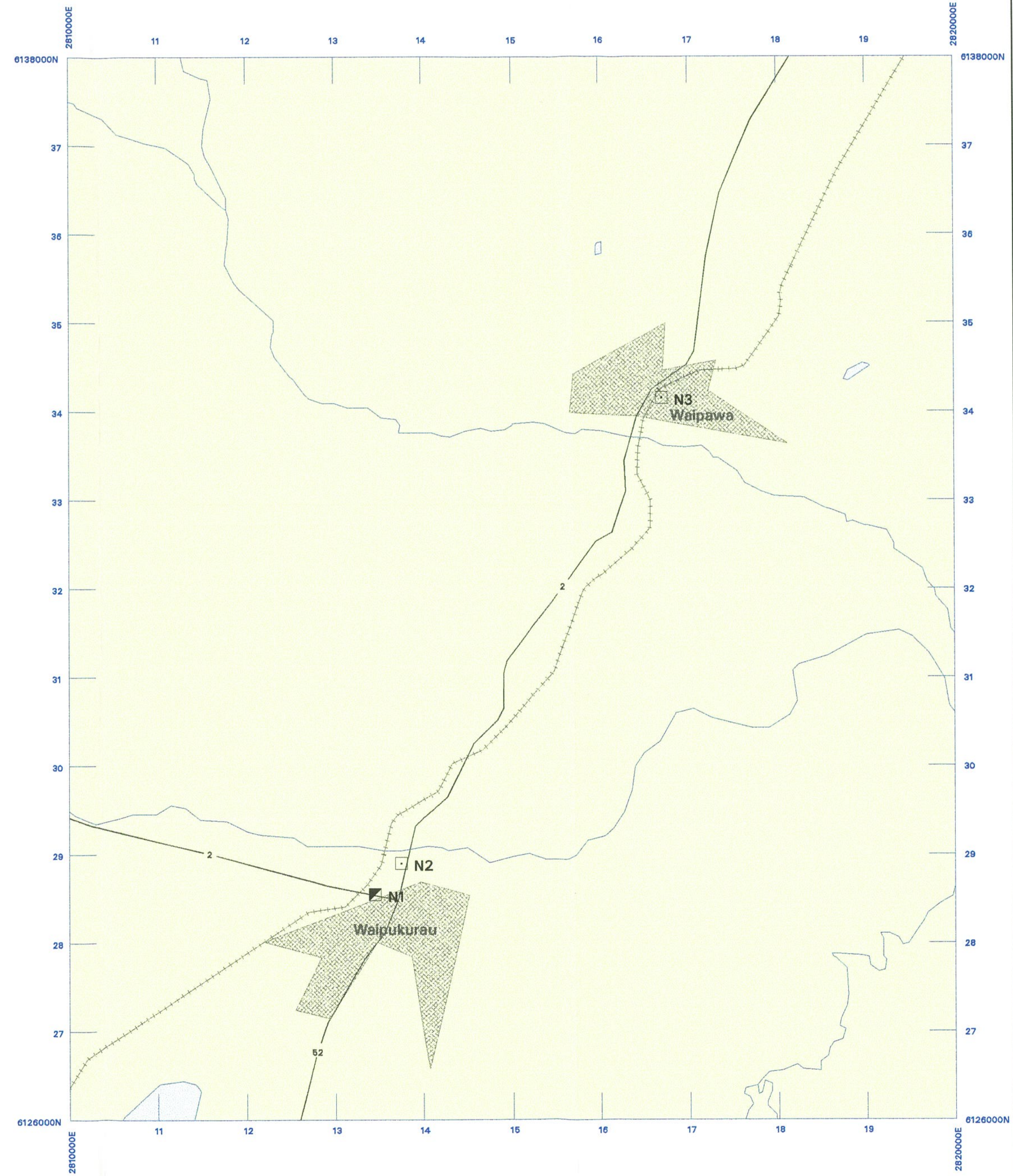
SCALE 1:50 000

1 0 1 2 3 4 5 6 kilometres



N6	Civil Defence, Hastings	2839800 6166100	YES @ 1.14 Hz	W2	~(Site 8)
N7	Kinns St/Kitchener St, Hastings	2840450 6167450	YES @ 1.20 Hz		
N8	Hastings Hospital, Omahu St/Hapuka St	2838500 6168100	YES @ 1.32 Hz	~W3	*c.f.* N30
N9	Chatham Rd/Flaxmere Ave, Flaxmere	2835100 6169200	YES @ 2.16 Hz	~W4	
N10	Chatham Rd extension, near golf course	2833200 6168200	NO		
N11	Iron Gate/Stock Rd, Flaxmere	2835300 6167000	NO		
N12	Ormond Rd at Ruapere Stream Bridge	2839850 6171300	YES @ 1.50 Hz	~W5	~(Site 6)
N13	Twyford Rd/Evans Rd	2836150 6171700	NO		
N14	SH50/Swamp Rd, Omahu	2833000 6173450	MAYBE @ 1.90 Hz		
N15	Pakowhai Rd	2841350 6172950	MAYBE @ 1.32 Hz		
N16	Farndon Rd/SH2, Clive River	2846200 6173250	YES @ 1.26 Hz	W6	~ Site 5 (200 m south)
N17	Tutaekuri River bridge, SE side	2846800 6174300	NO		
N18	Napier Airport carpark	2843150 6185850	YES @ 0.42 Hz		
N19	Embankment Rd (SE corner, Westshore domain)	2843500 6184050	YES @ 0.72 Hz	W10	~ Site 2 (400 m west)
N20	Napier Sailing Club	2844600 6183850	YES @ 0.90 Hz		1994 study
N21	Perfume Pt/East Pier, Barry St	2845200 6184400	YES @ 0.72 Hz	W9	~ Site 4 (± 200 m)
N22	Napier City Council Works Depot	2843400 6182100	YES @ 1.02 Hz	W8	1994 study
N23	Kennedy Park, Napier	2845100 6181550	NO		1994 study
N24	Tennyson St/Hastings St, Napier	2846950 6183200	NO		
N25	Hershell St/Browning St, Napier	2847000 6183300	NO		
N26	Nelson Park, Napier	2846250 6182400	YES @ 0.73 Hz		1994 study
N27	Thistle St/Georges Drive, Napier	2845800 6182050	YES @ 0.72 Hz		

N28	Napier Hospital, above operating theatres	2845350 6183200	MAYBE @ 3.00 Hz		
N28a	Napier Hospital, close to plant room	2845300 6183250	NO		
N29	Napier Airport, SCPT site	2842200 6185600	YES @ 2.00 Hz	~W11	~(Site 1)
N30	Hastings Hospital SCPT site	2838400 6168300	YES @ 2.00 Hz		~(Site 7)
	Pirimai Domain SCPT site	2843600 6181000			~(Site 3)
	Maryknoll (Weak ground motion study - reference site)	2840500 6179800		W7	

Notes: (1) The locations of N4 to N30, P3 & W7 are shown on Figure D-1 (in map pocket).
(2) The locations of N1-N3 are shown on Figure D-2.

4.0 RESULTS FOR THE HAWKE'S BAY REGION

The results of the Nakamura method applied to the collected microtremor data for the Hawke's Bay region vary from non-resonant to resonant with several sites showing complex multiple resonant peaks. The results are shown graphically in the plots that follow Figure D-2. At the complex sites the results are interpreted as being due to an interlayered stratigraphy, where there may be multiple soft and hard layer interfaces with the layers having different resonance characteristics. An example of such an area is in Napier, near Marine Parade (site N24), where beach deposits overlie thin lagoonal deposits, which in-turn overlie the finely layered alluvium which characterises much of the Heretaunga plains.

The sites which show clear signs of resonance include: Awarua Crescent at Havelock North Domain (N4), St Lukes School, Havelock North (N5), Hastings Civil Defence (N6), the Watties factory in Hastings (N7), Hastings Hospital (N8 & N30), Chatham Rd/Flaxmere Avenue in Flaxmere (N9), Farndon Road/SH2, Clive River (N16), Napier Airport Carpark (N18) and Napier Airport SCPT site (N29), Westshore Domain (N19), Napier City Works Depot (N22), Napier Sailing Club (N20), and Perfume Pt, Napier (N21).

Two sites (of the 31) show the classic resonant layer form, with a single resonant peak, and ratios which fall to less than one at high frequencies. These are Napier City Council works depot (N22), and Hastings Hospital (N8). In the case of Napier City Council works depot, an SCPT probe has already been undertaken. Notes of that investigation show that the CPT probing was stopped at 30m because fine sand jammed the friction cone. The seismic cone was only able to be advanced to 27m, presumably also a result of fine sands "locking up" and offering high resistance. It is therefore no surprise that the (incomplete) shear wave profile does not account for the observed resonant frequency. A frequency of 1.02Hz is measured, while 1.47Hz is expected on the basis of the profile to 27m. It is clear that 75ms is missing - this would amount to another 15m of material at 200m/s.

The Hastings Hospital site has been investigated by means of one SCPT probe (see Appendix G, Volume 2), one weak motion study site (see Appendix E, Volume 2), and two Nakamura ratio studies. The results of all these studies, which were carried out at slightly different locations within the hospital area, have important lessons for us.

The only datasets which may be directly compared are the SCPT profile (site 7 - refer to N30, Table D-1) and the Nakamura site N30 (Table D-1). Although the SCPT test shows a considerable depth of flexible material and shear-wave reflection, the Nakamura ratio is small. However, at the adjacent (initial) Nakamura site (N8) a dramatic resonance is seen. The weak motion site, W8, associated with Hastings Hospital, shows a resonant peak in the soil/rock spectrum, which is consistent with the frequency given by the Nakamura site N8. However, the amplitude of this peak is small. The propagation time for vertically propagating shear waves (shown by the SCPT test) is consistent with a resonant frequency of 1.7 Hz, making it likely that the SCPT probe at site 7 was not made at the deepest part of the alluvium. This is because the Nakamura ratio at site N8 gives a resonant frequency of 1.3 Hz which indicates a greater depth of alluvium.

In addition to the classic resonant responses seen at Napier City Council works depot, and Hastings Hospital, there are simple resonant peaks at Embankment Rd (N19), Napier Airport (N18), Napier Sailing Club (N20), and Perfume Point (N21). Each of these shows a ratio minimum just above the frequency of the resonance, but the ratio rises to moderate values thereafter. The meaning of this sort of plot is unknown, but a favoured explanation is the role of near surface stiff layers. A penetrometer probe at the Napier Sailing Club met refusal at 4m. These responses are not well understood, but it is highly probable that they indicate amplification.

The sites at Hastings Civil Defence (N6), Hastings Watties Factory (N7), Flaxmere (Chatham Rd/Flaxmere Ave) (N9), and Clive (Farndon Rd/SH2) (N16), all have complicated peak structures, but with the fall off at high frequencies expected of resonances. These are best considered complicated multiple resonances, and are places where amplification should be expected.

The site Ormond Rd/Raupare Stream site (N12) has both the complex resonance look and the failure to fall off at high frequencies that may be due to stiff near-surface layers. This curve is difficult to interpret in an unequivocal manner.

The sites at Nelson Park (N26), Thistle St/Georges Drive (N27) and Kennedy Park (N23), are challenging. There appears to be a pervasive peak at 0.72Hz for these sites, but it is small, and coupled with quite large ratios at high frequencies. It is possible that there is a flexible structure/layer under the gravels that were encountered during penetrometry.

The sites at Northumberland St/Russel St (Waipukurau) (N1), bridge (Waipukurau) (N2), Waipawa Post Office (N3), Chatham Rd extension near golf course (Flaxmere) (N10), Irongate Rd/Stock Rd (Flaxmere) (N11), Pakowhai Rd (N15), Tennyson St/Hastings St (Napier) (N24), Twyford Rd/Evans Rd (N13), SH 50/Swamp Rd (N14), Tutaekuri bridge (SE side) (N17), Museum (Herschell St) (N25) and Napier Hospital (N28 & N28a), all appear to be non-amplifying on the basis of these tests.

The nature of the materials of Bluff Hill, and of the flats surrounding it, will give rise to greater damage on Bluff Hill ("firm" soil) during strong shaking (as seen in 1931). This is relatively unusual (historical accounts usually describe greater damage on soft soil). The reason for this is that amplification is driven by soil flexibility but limited by soil strength. In the case of Napier the shear wave velocities (hence flexibilities) on Bluff Hill and the surrounding flats (the part with buildings in 1931) are similar, but the hill has greater strength than the flats, and maintains amplification to high strains and thus causes greater damage. This can be expected to occur again (but of course the parts of the estuary reclaimed and built on since 1931 are considerably more flexible and will amplify more).

6.0 REFERENCES

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Ohmachi, T., Nakamura, Y., and Toshinawa, T., 1991: Ground motion charateristics of the San Francisco Bay area detected by microtremor measurements. *Proceedings: Second International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, March 11-15, 1991, St Louis, Missouri, Paper No LP08.*

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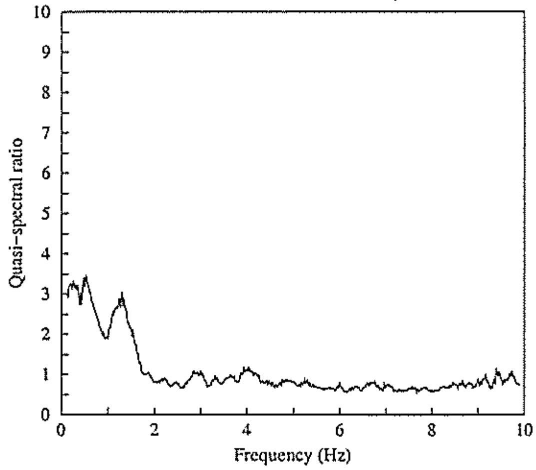
Hawkes Bay Quasi–Spectral Ratios

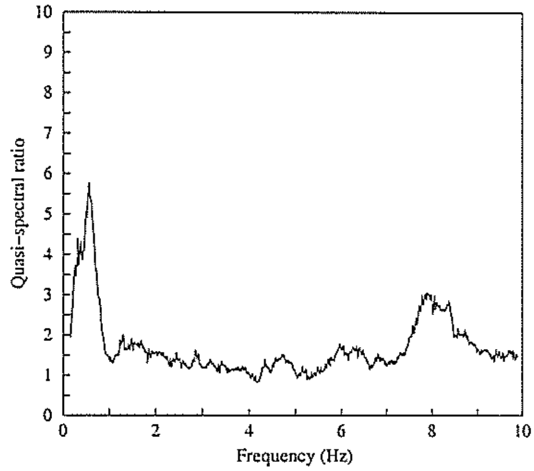
Site N1

Northumberland St / Russel St, Waipukurau



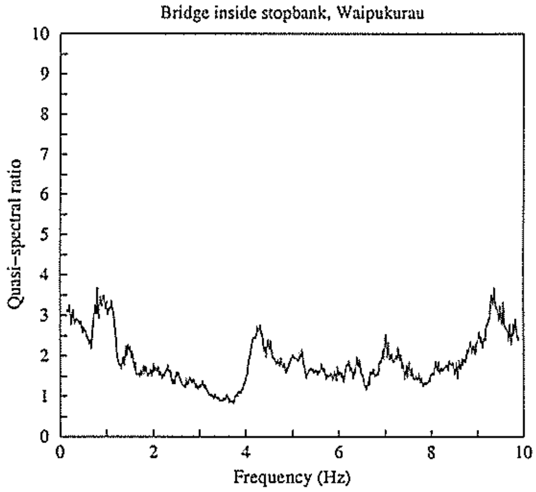
Site N4

Awarua Cresc at Havelock Nth domain



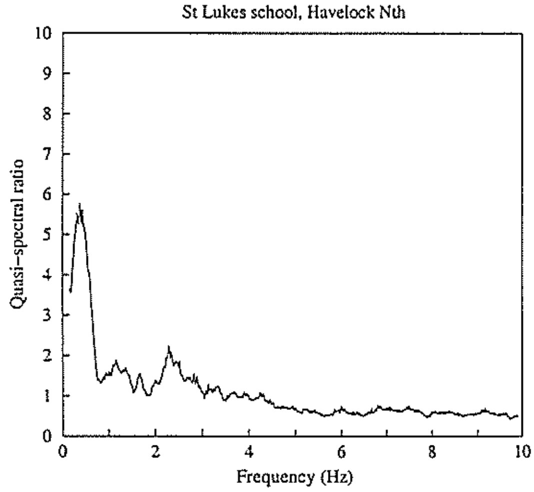
Site N2

Bridge inside stopbank, Waipukurau



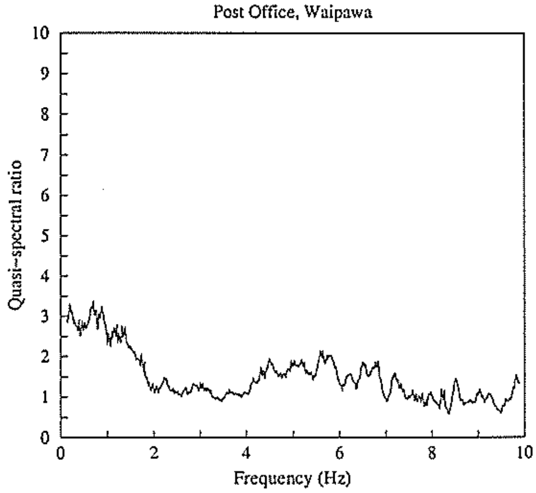
Site N5

St Lukes school, Havelock Nth



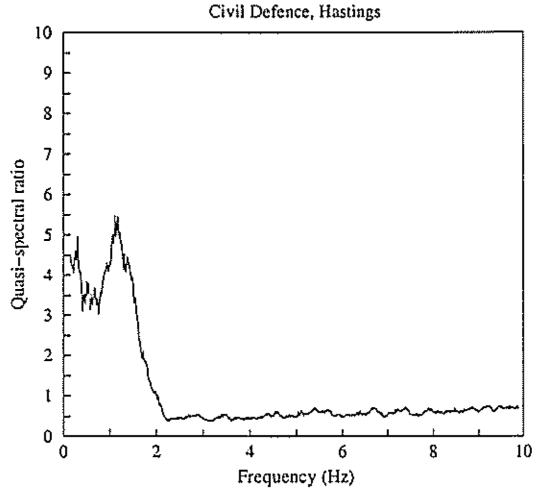
Site N3

Post Office, Waipawa



Site N6

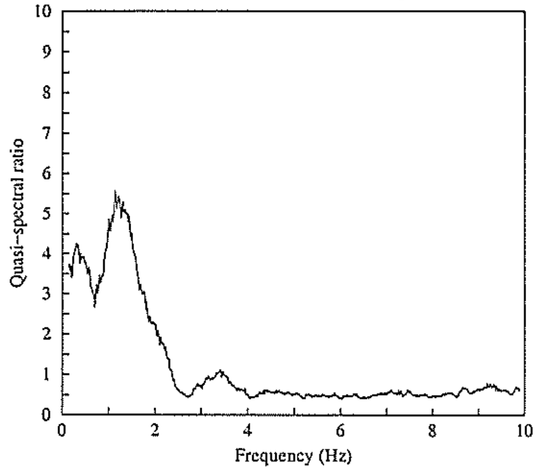
Civil Defence, Hastings



Hawkes Bay Quasi–Spectral Ratios

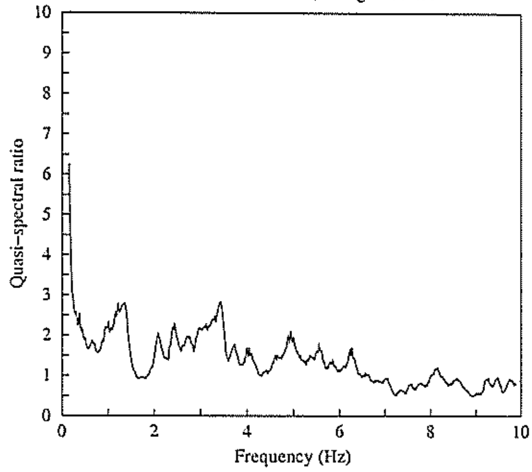
Site N7

Kinns St / Kitchener St, Hastings



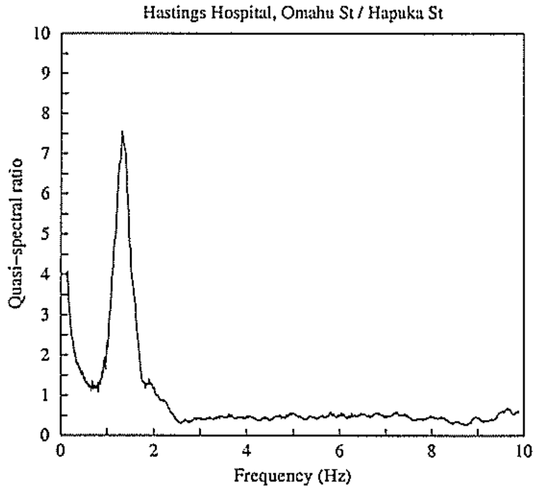
Site N10

Chatham Rd extension, near golf course



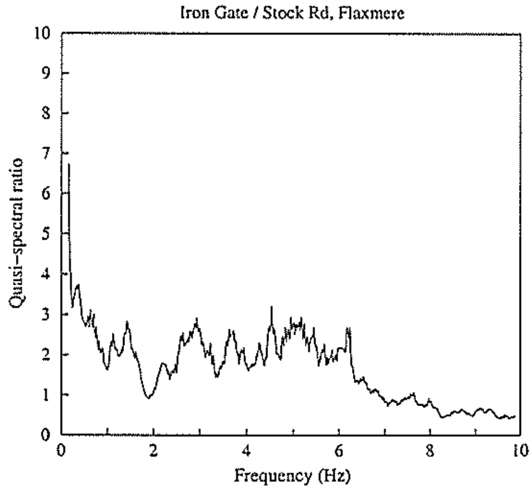
Site N8

Hastings Hospital, Omahu St / Hapuka St



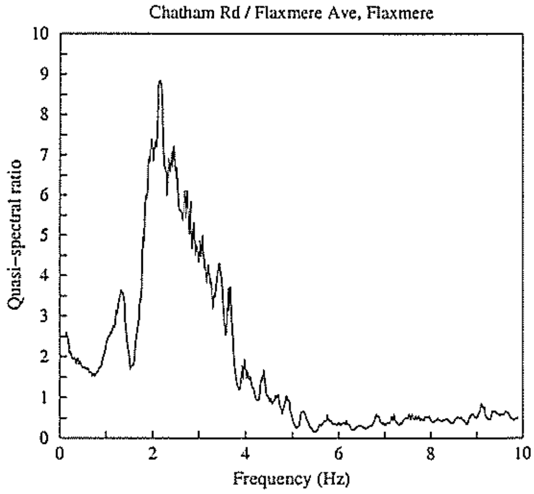
Site N11

Iron Gate / Stock Rd, Flaxmere



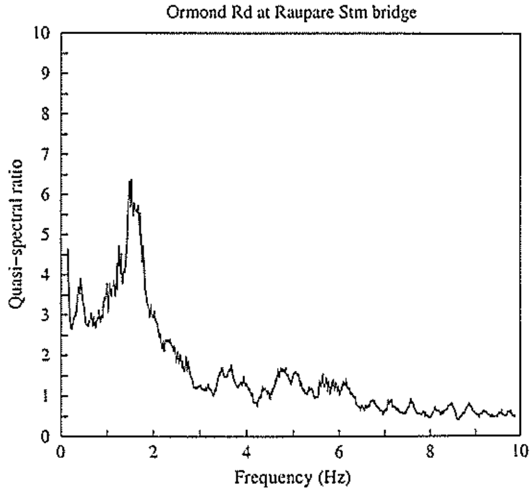
Site N9

Chatham Rd / Flaxmere Ave, Flaxmere



Site N12

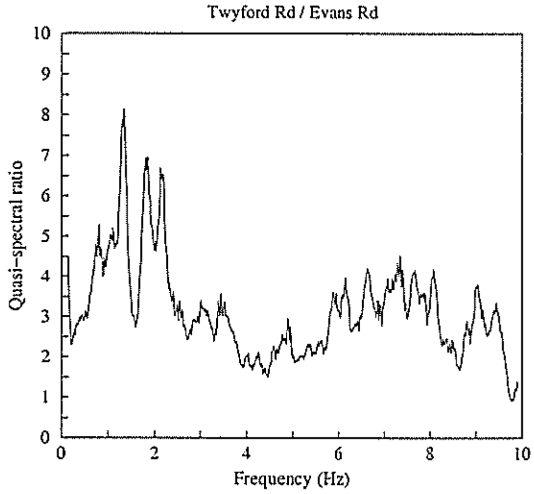
Ormond Rd at Raupare Stm bridge



Hawkes Bay Quasi–Spectral Ratios

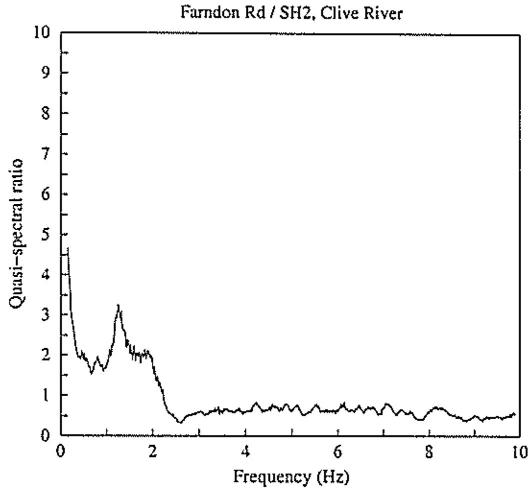
Site N13

Twyford Rd / Evans Rd



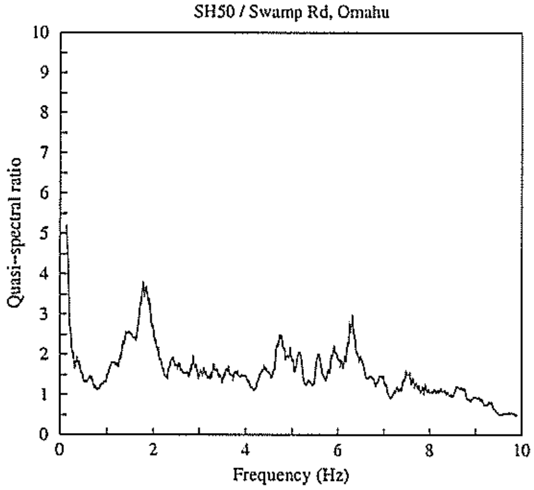
Site N16

Farndon Rd / SH2, Clive River



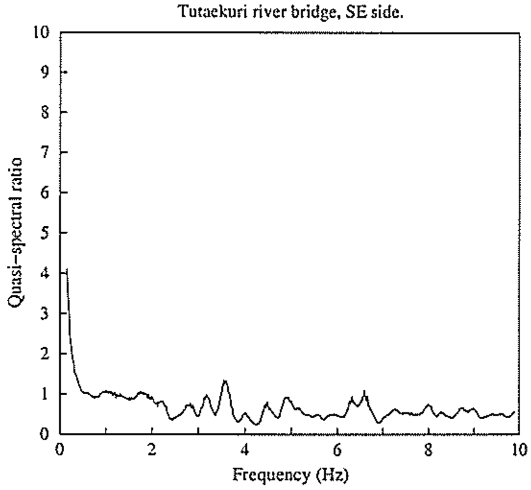
Site N14

SH50 / Swamp Rd, Omahu



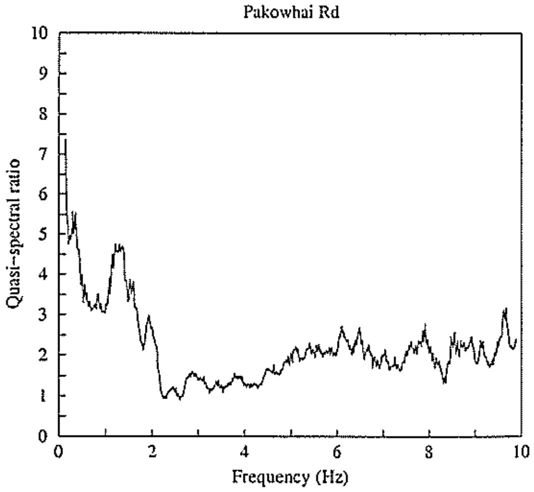
Site N17

Tutaekuri river bridge, SE side.



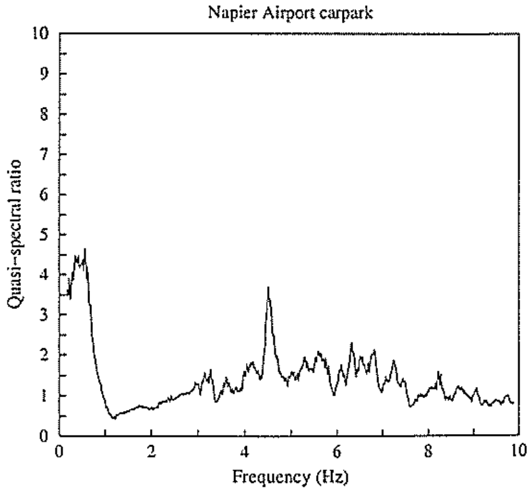
Site N15

Pakowhai Rd



Site N18

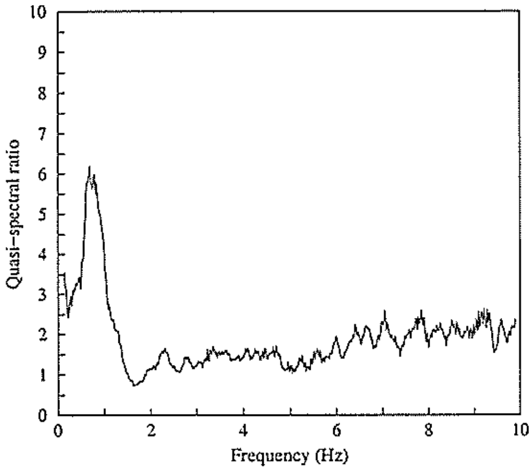
Napier Airport carpark



Hawkes Bay Quasi–Spectral Ratios

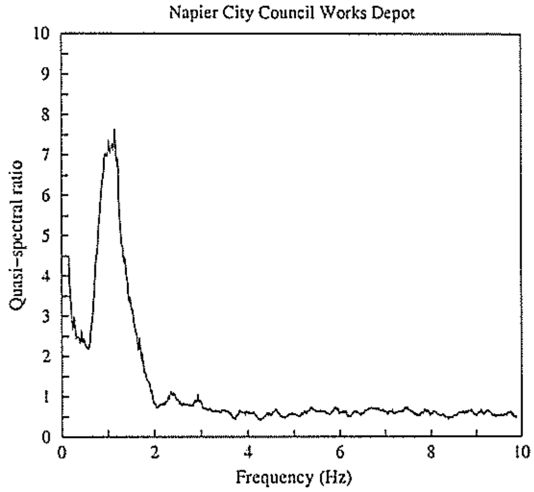
Site N19

Embankment Rd (SE corner, Westshore Domain)



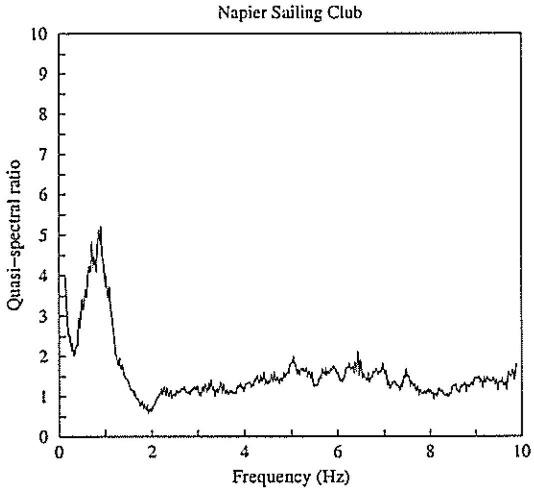
Site N22

Napier City Council Works Depot



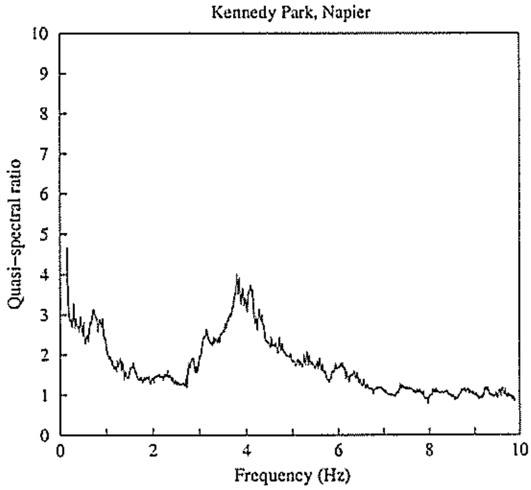
Site N20

Napier Sailing Club



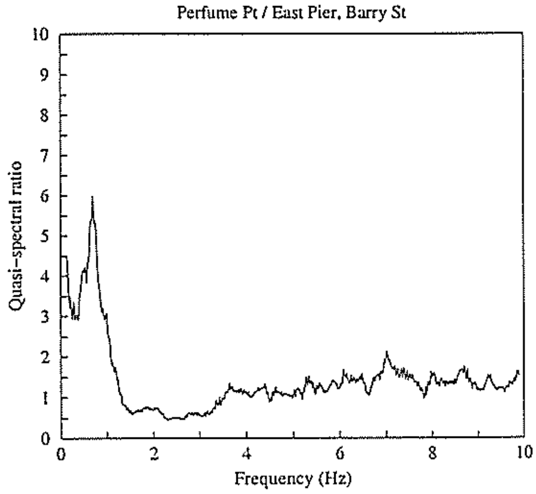
Site N23

Kennedy Park, Napier



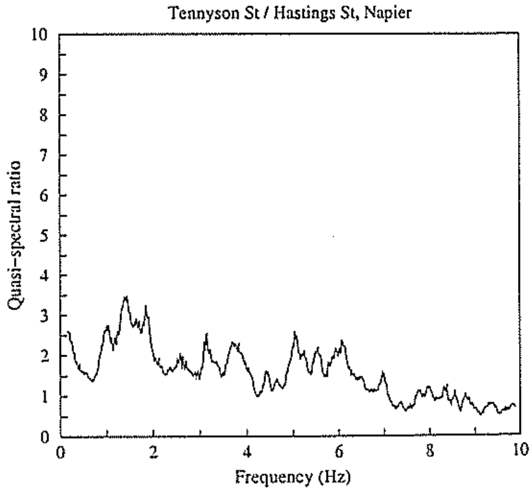
Site N21

Perfume Pt / East Pier, Barry St



Site N24

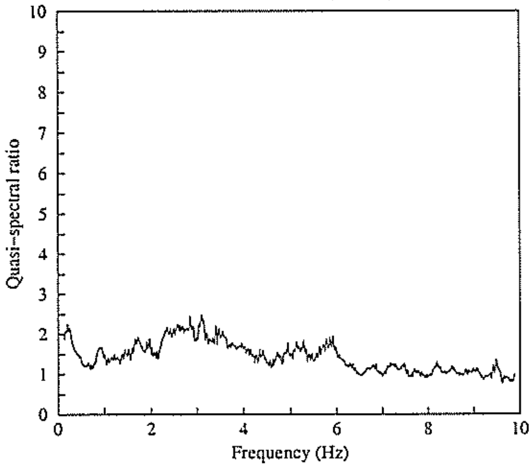
Tennyson St / Hastings St, Napier



Hawkes Bay Quasi–Spectral Ratios

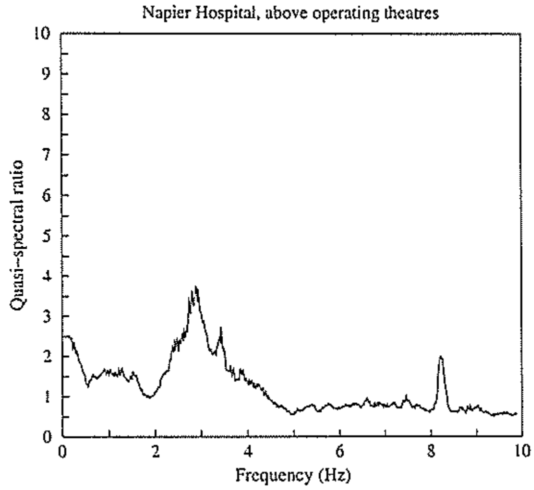
Site N25

Herschell St / Browning St, Napier



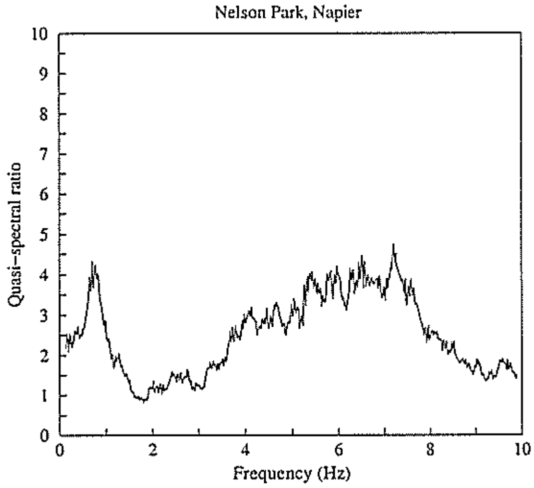
Site N28

Napier Hospital, above operating theatres



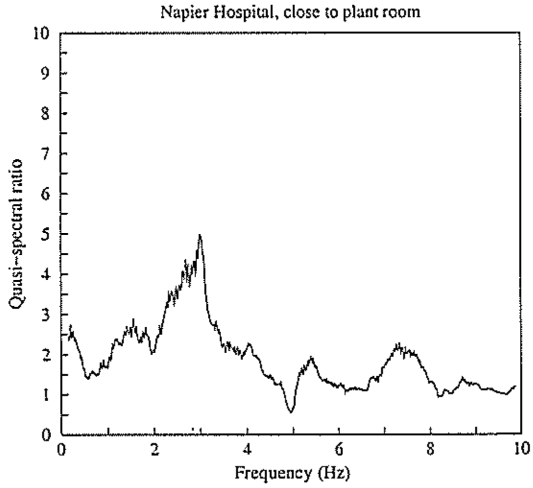
Site N26

Nelson Park, Napier



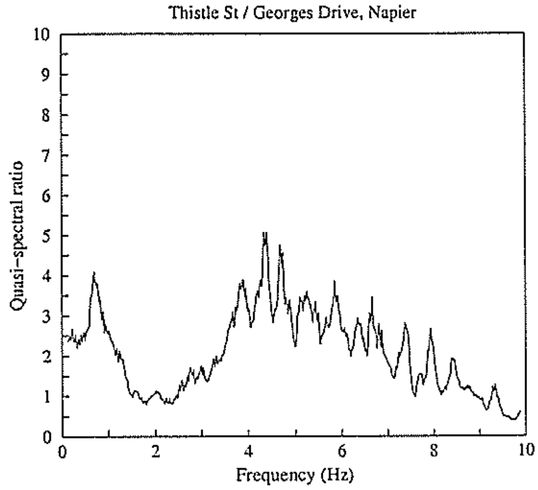
Site N28a

Napier Hospital, close to plant room



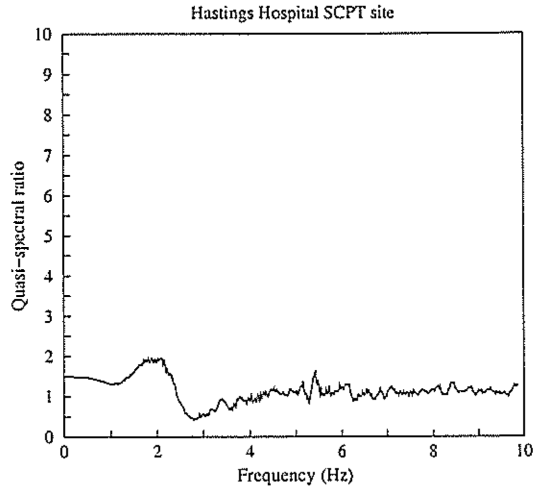
Site N27

Thistle St / Georges Drive, Napier



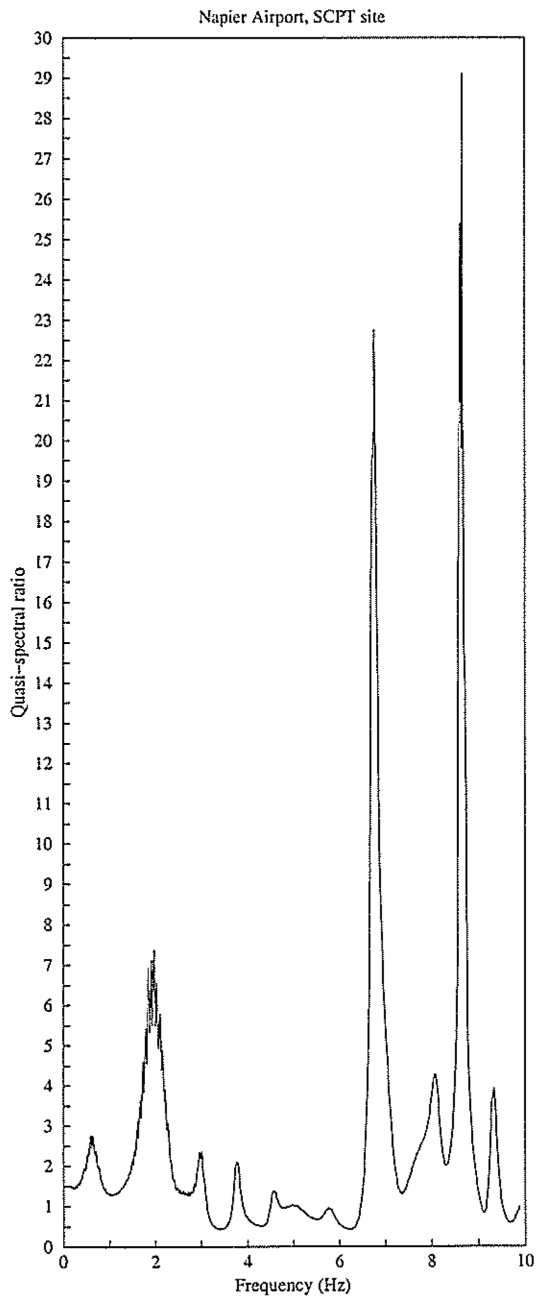
Site N30

Hastings Hospital SCPT site



Hawkes Bay Quasi–Spectral Ratios

Site N29



APPENDIX E

WEAK GROUND MOTION MEASUREMENTS

HAWKE'S BAY REGIONAL COUNCIL
EARTHQUAKE HAZARD ANALYSIS PROGRAM
STAGE III

WEAK GROUND MOTION MEASUREMENTS

SUMMARY

This appendix describes the methodology used in the acquisition and analysis of weak ground motion data. These are measurements of motions generated from small to moderate earthquakes located at moderate to large distances. A network of seismographs was temporarily installed to collect the ground motion data. Data has also been utilised from a previous study (Benites and Haines, 1996).

Strong amplification of small ground motions at some alluvial sites means that significant local damage could be caused at such sites by a moderate earthquake that would cause no damage at a firm site. If the comparison of strong and weak motions in other areas can be applied to the Hawke's Bay, the moderate amplification factors recorded at most sites may remain the same for strong ground motion, while the large amplifications at short period measured for weak motion on the softest sites are likely to be decreased for larger earthquakes. Thus, the high amplifications at short period at site SLN in Napier, for example (Figure E-1), must be considered as an upper bound on the amplification of shaking to be expected during a large earthquake.

Both the observed and synthetic ground motions modelled by Benites and Haines (1996) in the Bluff Hill area are consistent with the damage distribution due to the 1931 Hawke's Bay M=7.8 earthquake.

In general, the sites in the Heretaunga Plains alluvium show amplifications between 1 and 3 Hertz. In the lagoonal deposits the mean soil/rock ratios indicate that amplification occurs more at the moderate to long period, low frequency end of the spectra (0-2 Hz).

1.0 INTRODUCTION

Weak ground motion caused by earthquakes has been studied to determine the areas within Hawke's Bay where greater levels of shaking can be expected in damaging earthquakes. The recorded ground motions are generally much smaller than the motions which cause damage, and thus the results are presented in terms of relative levels of shaking between sites. The amplitude response of each site relative to a reference site is defined as the amplification and is presented as a function of frequency so that the effect of ground motion on different sized structures can be estimated.

Weak ground motions resulting from small to moderate magnitude earthquakes located at moderate to large distances are recorded simutaneously at a variety of sites to measure the relative levels of shaking.

Data from several weak motion sites occupied during a previous study (Benites and Haines, 1996) were incorporated in this assessment to maximise use of existing data and to extend the geographic coverage of the survey. Both surveys have the same reference site.

2.0 PREVIOUS STUDIES

The initial study investigating weak ground motions in the Hawke's Bay area was carried out by Rafael Benites and John Haines of IGNS during 1994 and was reported in Benites and Haines (1996). In brief, this study carried out an experiment to measure weak seismic motion in the city of Napier. Eighteen digital seismographs were deployed in the area known as Bluff Hill. Each station consisted of an EARSS (Equipment for Automatic Recording of Seismic Signals) digital recording system, developed in New Zealand by IGNS, and a three-component L4C-3D seismometer of 1 Hz natural period.

The reference site was at Saint Peter's Mission in Greenmeadows 6-8 km to the southwest. (This makes direct comparison with the data obtained for this study possible - i.e. same reference site, although a different set of seismic data is used).

Twenty-three earthquakes were selected from the data set of all recorded events. The epicentres of these selected earthquakes cover a wide range of azimuths with respect to Napier and their depths ranged from 16-190 km, while their magnitudes ranged from M_b 2.1 to 5.4. The analysis of this data set showed that on or near the Bluff Hill the degree of amplification experienced at a site was frequency dependent (Table E-1).

Table E-1: The relationship between the greatest measured amplifications of horizontal motion and the frequency of shaking at which these amplifications occurred for sites on or near the Bluff Hill in Napier (after Benites and Haines, 1996). (All amplifications are reported with respect to the reference station at Saint Peter's Mission, Greenmeadows).

Location	NE hill	Flats	SW hill	Flats
Frequency (Hz)	1.5	2	3	13-14
Amplitude (amplification factor)	2	3	2	3.5

Of the eighteen deployed seismographs, two were on soft soil sites (Dowrick *et al*, 1995). These were sites SLN and HSN (Figure E-1). The results for these two stations were very different to all the other 16 stations, with these two showing larger variability, scatter and amplification. The responses of HSN and SLN are similar and show significant amplification at several frequencies in the 15 Hz range for both horizontal components. The largest value of the ratio is 3-4 at about 2 Hz for HSN, and 3-4 at 2.0-2.5 Hz and 14.5 Hz for SLN. The responses of the sites of stations SLN and HSN exhibit consistently larger amplifications than any other sites.

Stations DHN, HNN and VMN although not on the hill are in a similar environment to each other (firm soil, beach environment) (Figure E-1). VMN had the third highest measured amplifications of the sites while HNN showed consistently small or no amplification. The results for these two stations show the variability that can occur in shaking response within the same geological unit. Amplifications for DHN are not reported by Benites and Haines (1996) although Figure E-4 presents the results.

3.0 THIS STUDY

Eleven sites in and around the Heretaunga Plains were occupied including a reference site during the weak motion study undertaken for this project. The underlying stratigraphy of the sites chosen ranged from bedrock (weak Tertiary age sandstone, siltstone and limestone in the Hawke's Bay region) to thick, soft fine-grained marine sediment, and were located to establish the ground response on a range of near-surface geological units identified from the geological mapping (Figure B-2). The sites where recording stations were set up had all been previously measured using the Nakamura approach as a screening tool.

The seismographs deployed were EARSS portables which use Mark Products L4C-3D seismometers which have a natural frequency of 1 Hz. The installation took place during June 1997 and the deployment lasted until the end of July 1997. The reference site at Saint Peter's Mission in Greenmeadows was located on Tertiary-age marine sedimentary rocks. This site is not stiff bedrock and amplifications reported with respect to it are smaller than would be reported for stiff bedrock.

Broadband recordings were made for sites in Hastings, Flaxmere, Napier, Twyford, Havelock North, and the reference site (Sites W1-W11, Figure D-1 - in map pocket, see Table D-1 for location references). For each site the spectrum of horizontal motion was obtained by taking the root-mean-square of the spectra for the north and east components and smoothing the resultant. Spectral ratios were computed by dividing the root-mean-square horizontal spectrum for each station by the corresponding value for the reference station, for each earthquake. The mean value of the spectral ratio taking all recorded earthquakes into account, was also calculated.

The results of these analyses are shown on Figures E-5 to E-14. In general, the sites in the Heretaunga plains alluvium (f3, f4, f5, and f6, Figure B-2 - in map pocket) includes sites W1, W2, W3, W4, W5, & W6, (Figure D-1 - in map pocket (refer to Table D-1 for location references)). Figures E-5 (W1), E-6 (W2), E-7 (W3), E-8 (W4), E-9 (W5) and E-10 (W6) (at the end of this appendix) present the results in graphical form for sites W1 to W6 and these results show amplifications occurring between 1 Hz and 3 Hz in the Heretaunga plains alluvium. The mean soil/rock ratios for these sites at natural frequencies between 1 and 4 Hertz are shown in Table E-2.

In the lagoonal deposits (l1 and l2, Figure B-2; sites W8, W10 & W11, Figure D-1 & Table D-1; & Figures E-11 (W8), E-13 (W10), E-14 (W11)) the mean soil/rock ratios indicate that amplification occurs more at the moderate to long period, low frequency end of the spectra (0-2 Hz). The mean soil/rock ratios are shown in Table E-2 for natural frequencies in the range of 1 to 4 hertz. As shown on Figures E-2 to E-14 and in Table E-2 the mean soil/rock ratios show a consistent pattern with respect to the geological units. This finding suggests that amplification factors developed may reasonably be applied to the geological units in developing the site response classifications for the region.

Table E-2: Mean soil/rock ratios (amplification factors) for horizontal motion as a function of frequency for different geological units with respect to the reference site.

	Natural Frequency (Hz)			
Geological Unit	1	2	3	4
Heretaunga Plains alluvium (f3, f4, f5, & f6)	2.16	2.01	2.25	0.66
Beach deposits (b) [dhn, vmn, hnn]	1.60	0.70	1.00	0.70
Lagoonal deposits (l1 & l2)	3.08	1.46	1.15	0.70

4.0 DISCUSSION

Soils do not always react the same way to strong shaking as they do to weak shaking. Therefore it is important to determine the extent to which the relative weak motion responses can be extrapolated to the stronger motions that cause damage during earthquakes. Data obtained from the 1988 Armenian earthquake (Borcherdt et al., 1989) indicated peak frequencies determined from spectral ratios for aftershocks of the 1988 earthquake were similar to the natural period of the buildings most heavily damaged in Leninakan during the mainshock. Further, the greatest damage occurred in the areas with the highest spectral ratios between rock and soil. These observations suggested that weak motion data (like that from aftershock records) can provide a useful indication of likely effects at damaging levels of ground shaking. Additional examples of the applicability of weak motion data to predict damage during strong ground motions come from California. Intensity maps based on weak motion data for San Francisco have been shown to have anticipated all the areas that experienced significant damage during the 1989 Loma Prieta earthquake (Borcherdt, 1991).

However, the absolute levels of amplification of strong and weak motions do not always correlate. Small amplification factors (factors of 2-3) have been shown to persist to 0.7 g in soft soils in California (Jarpe et al., 1988) and to 0.2g in Garm, USSR (Tucker & King, 1984), but ground motion amplifications were greater for some aftershocks of the 1989 Loma Prieta earthquake in California than for the mainshock at some sites. For one pair of sites, the maximum spectral ratio was 8 for the aftershocks but only 3 for the mainshock (Jarpe et al., 1989). This, however, is an extreme example of non-linear behaviour, as soils liquefied after 5 seconds of shaking during the mainshock.

Borcherdt (1991) found that the correlation of average spectral ratio with shear wave velocity of the top-most 30 m of sediment was nearly the same for strong and weak motions, when a broadband average from 0.5 to 2.5 Hz was considered. This is the frequency range most important for large engineered structures. Averaging over a range of frequencies reduces the effect of narrow resonance peaks and emphasises the importance of low frequency shaking.

5.0 REFERENCES

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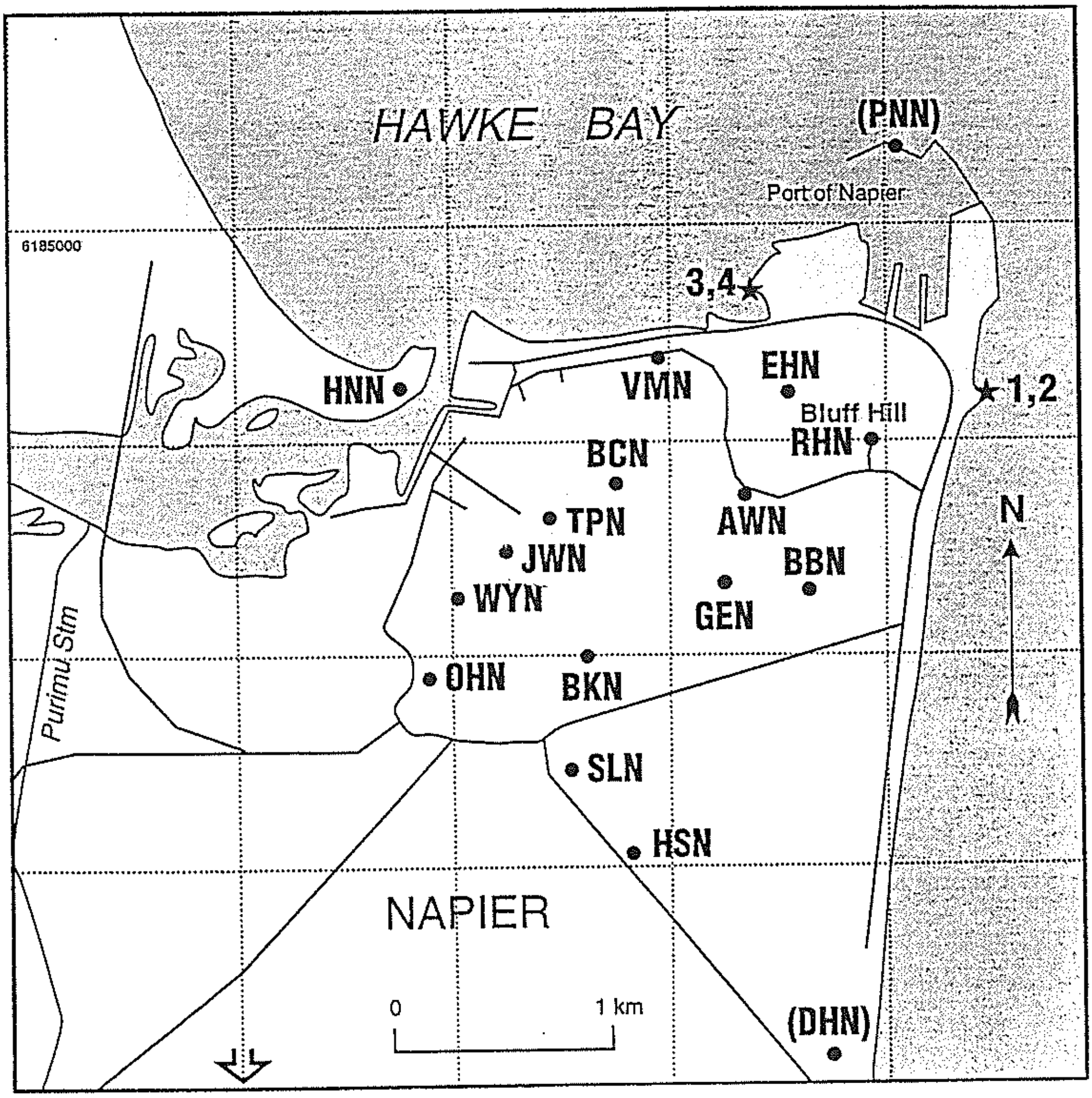

Figure E-1: Locations of weak motion stations used in the Benites and Haines (1996) study.

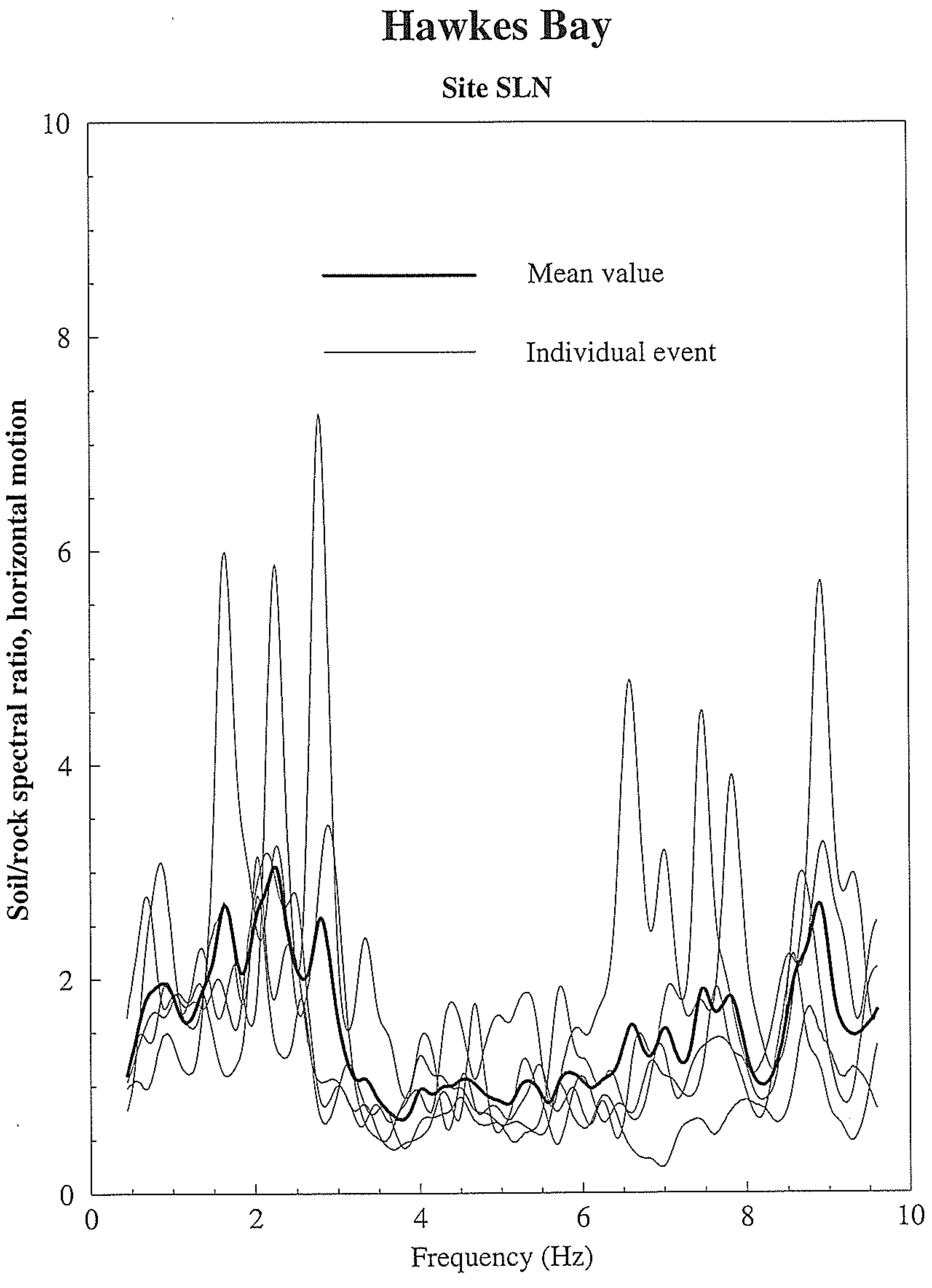

Figure E–2: Soil/Rock spectral ratios at SLN (Napier South)

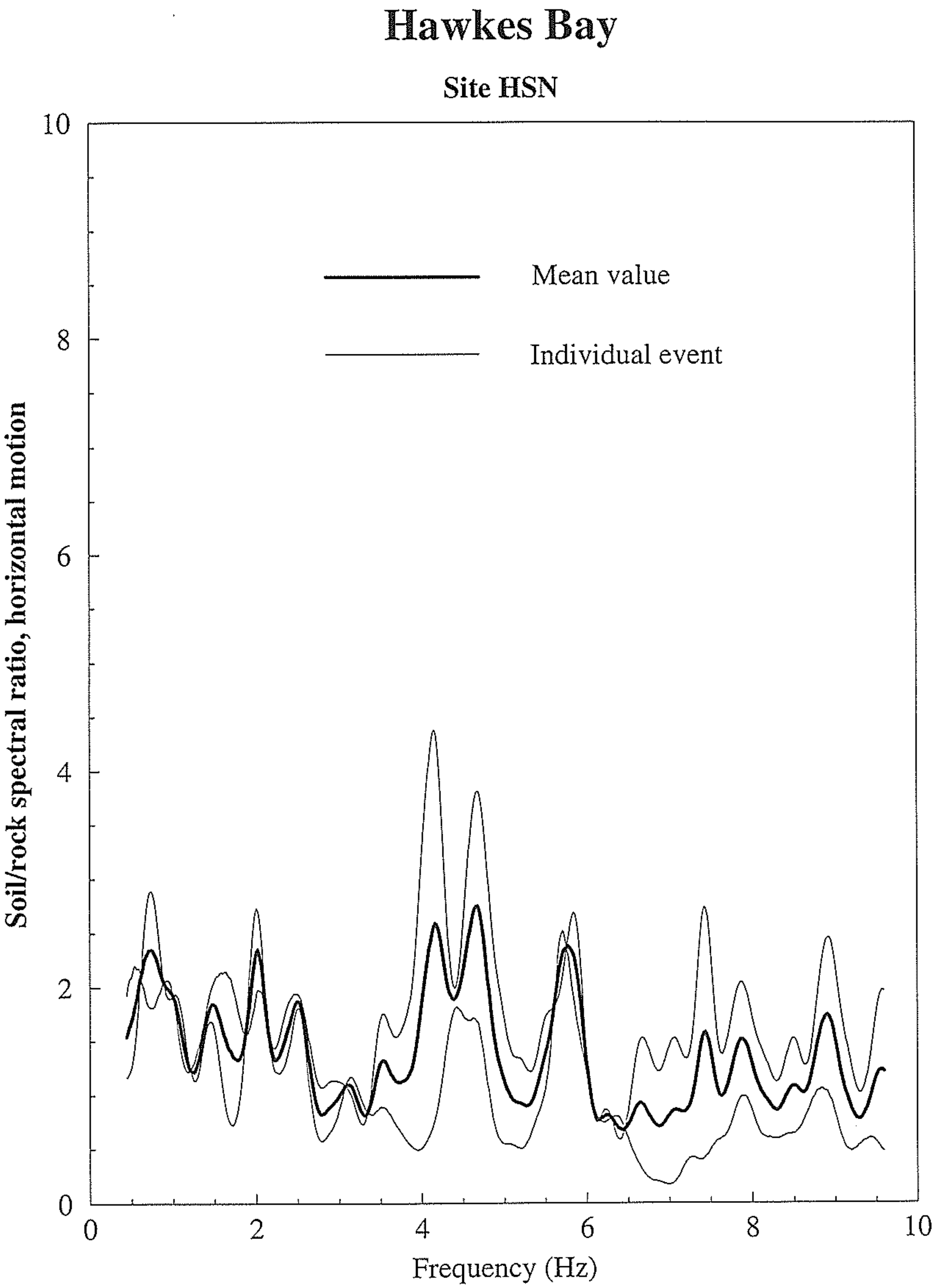

Figure E–3: Soil/Rock spectral ratios at HSN (Napier South)

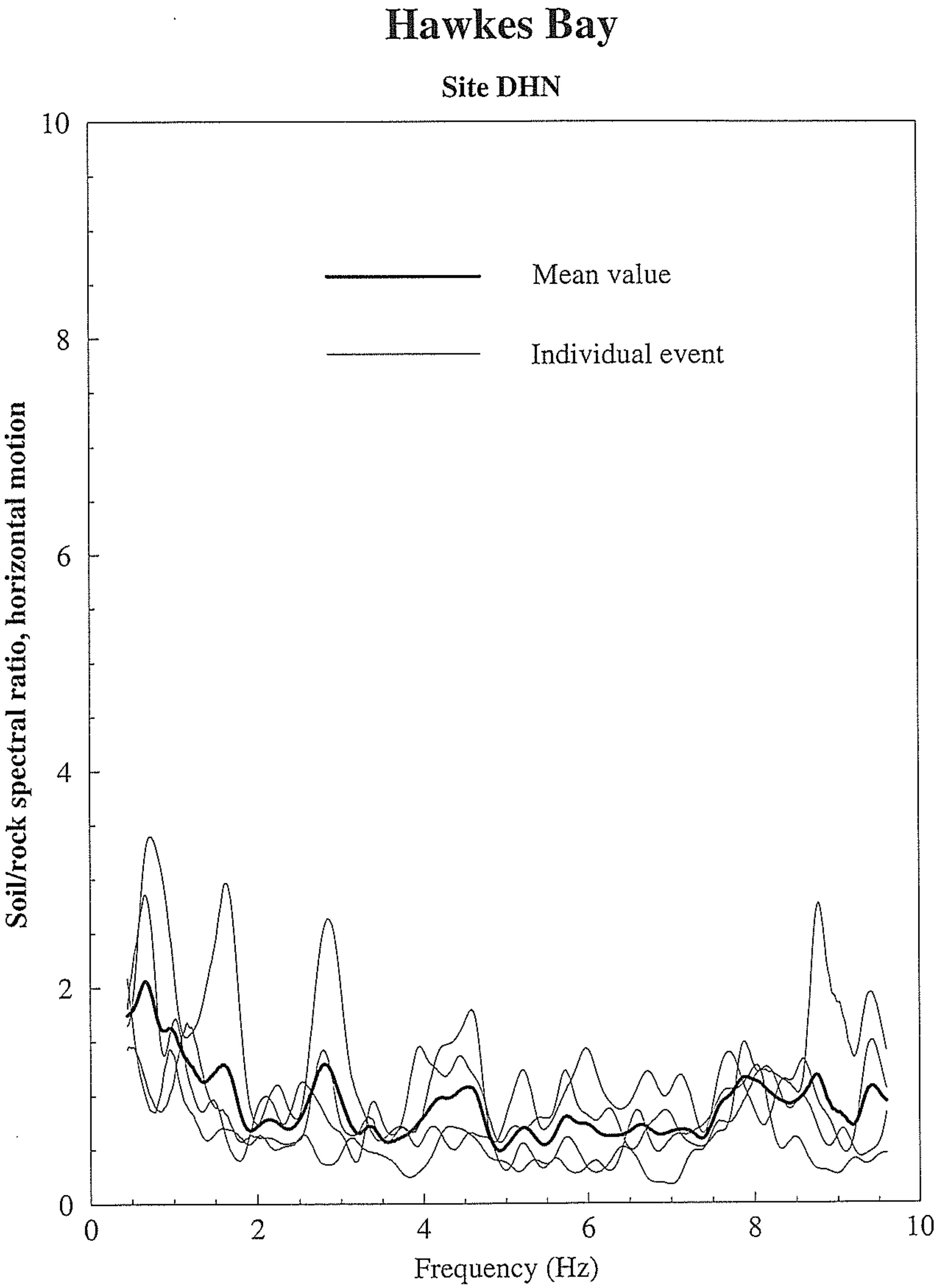

Figure E–4: Soil/Rock spectral ratios at DHN (Te Awa)

Hawkes Bay

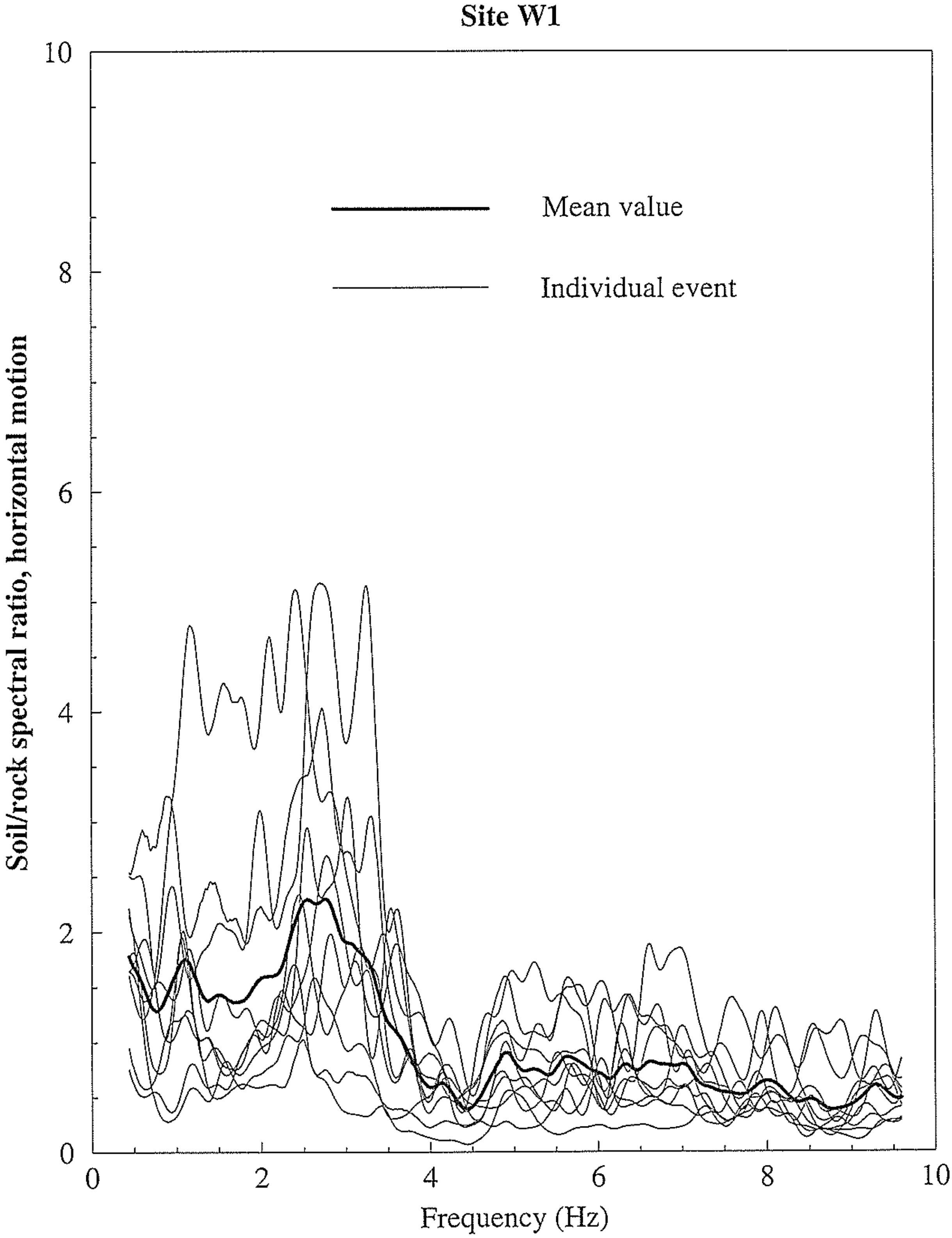

Figure E–5 : Soil/Rock spectral ratios at Havelock North Primary School

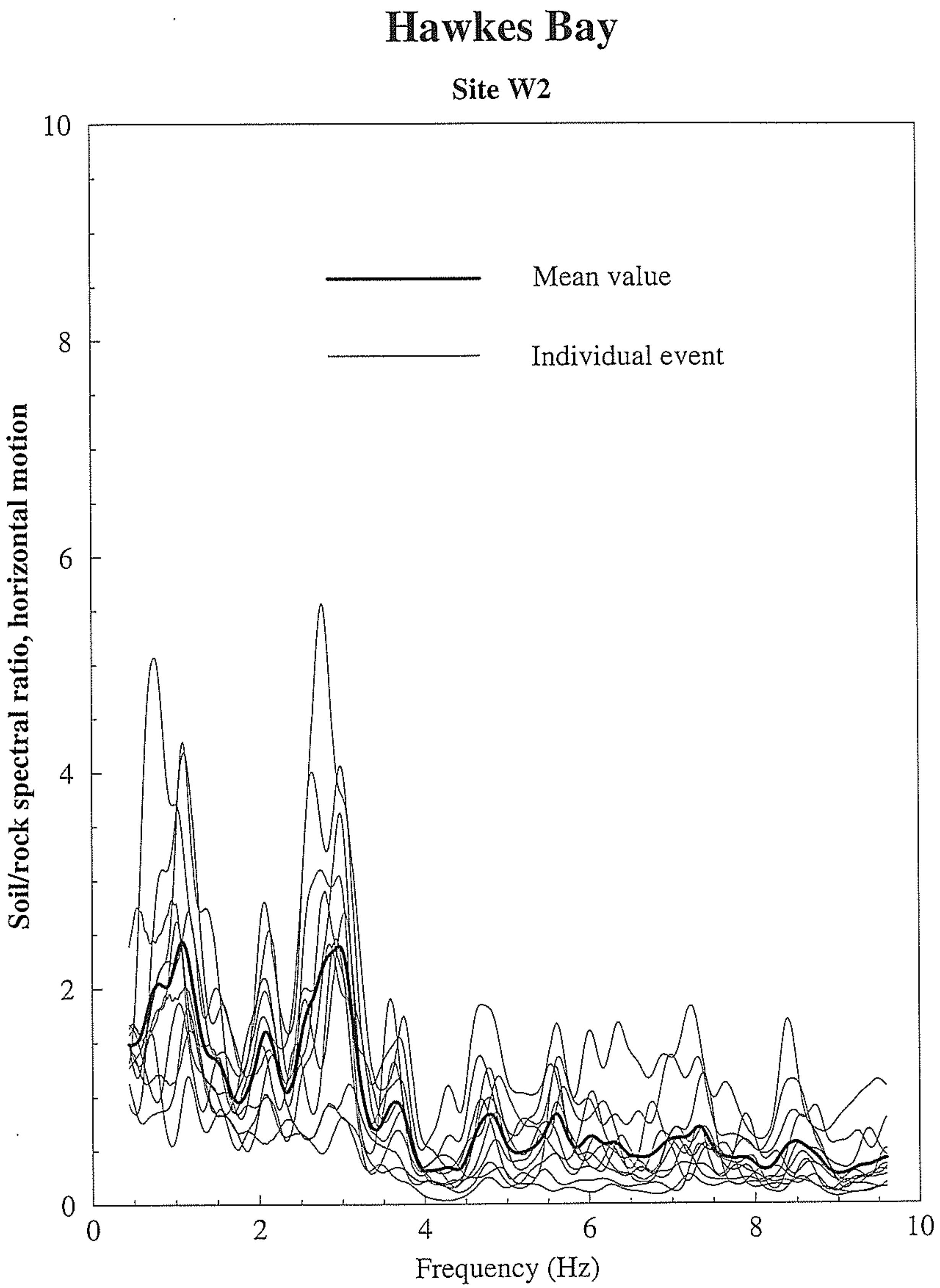

Figure E–6 : Soil/Rock spectral ratios at Hastings Civil Defence

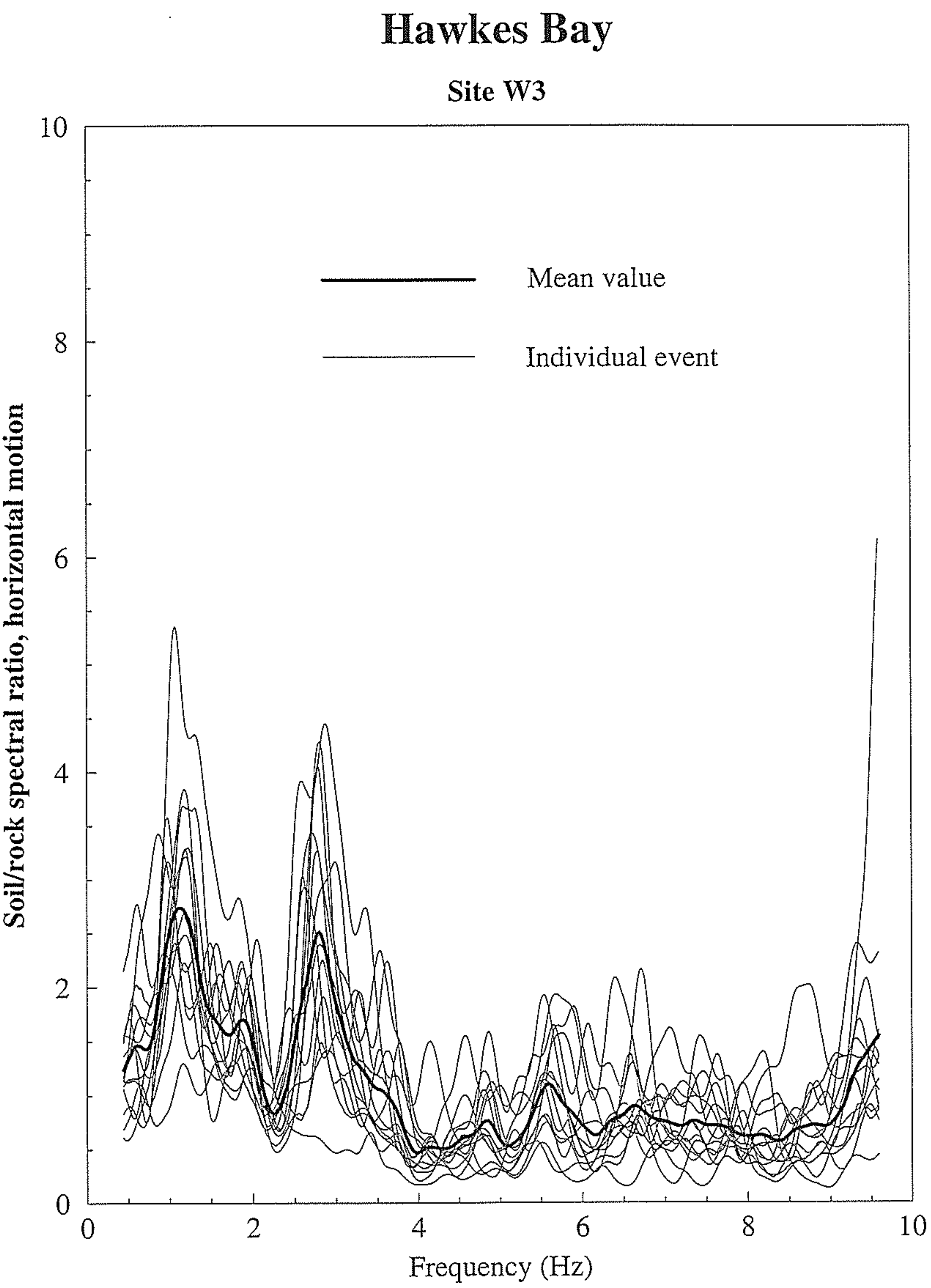

Figure E–7 : Soil/Rock spectral ratios at Hastings Hospital

Hawkes Bay

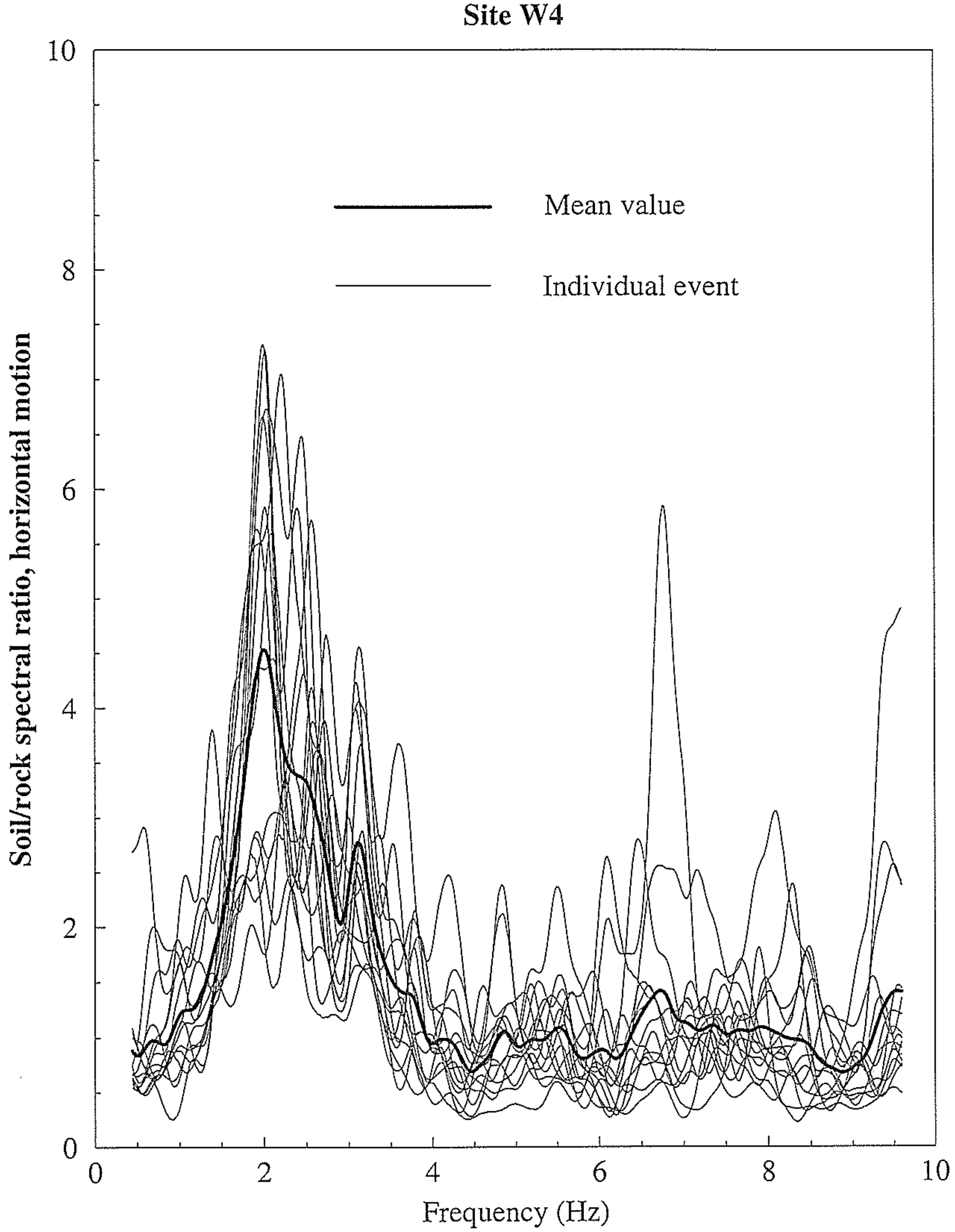

Figure E–8 : Soil/Rock spectral ratios at Flaxmere

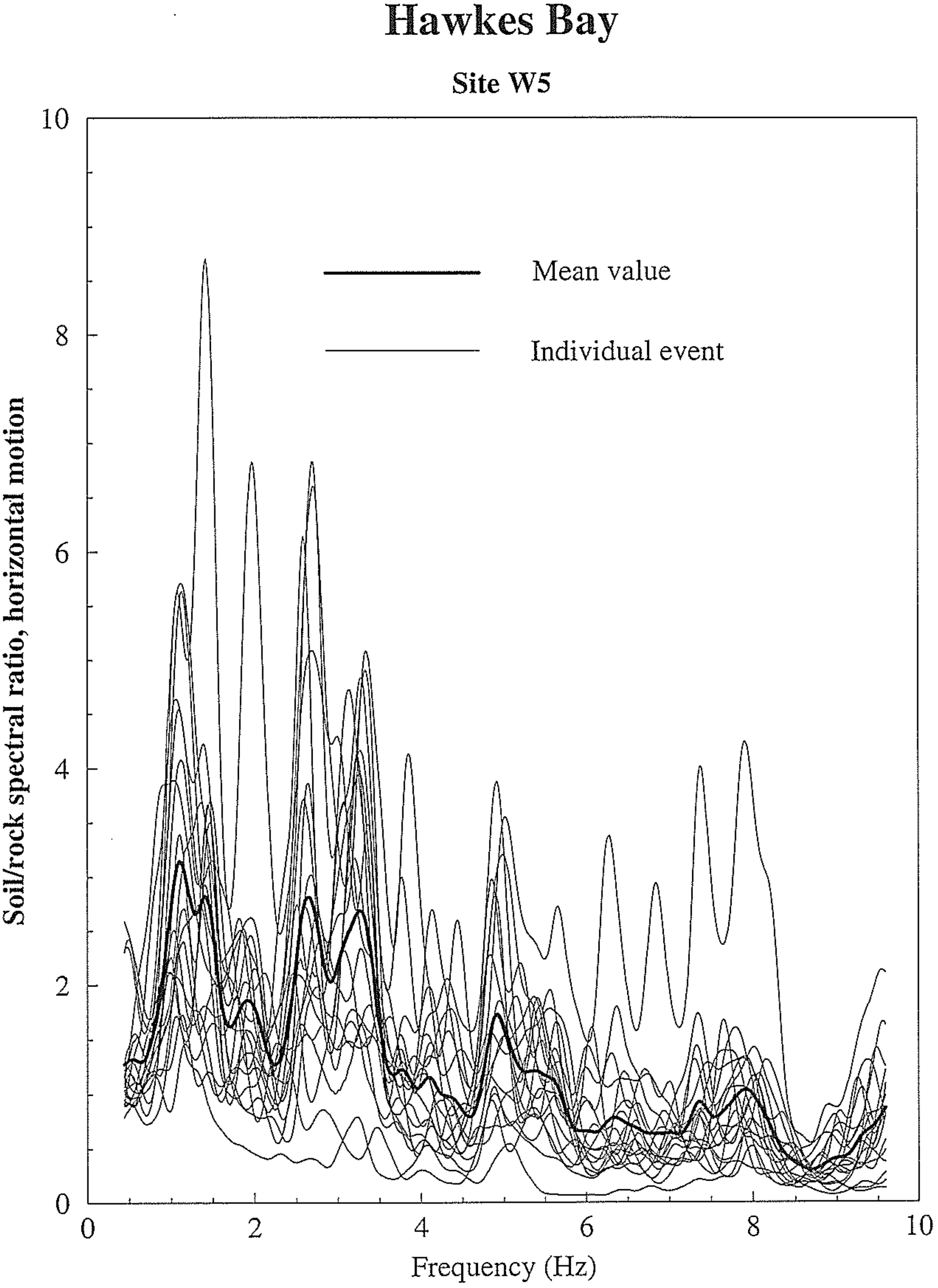

Figure E–9 : Soil/Rock spectral ratios at Ormond (Ruapere Stream)

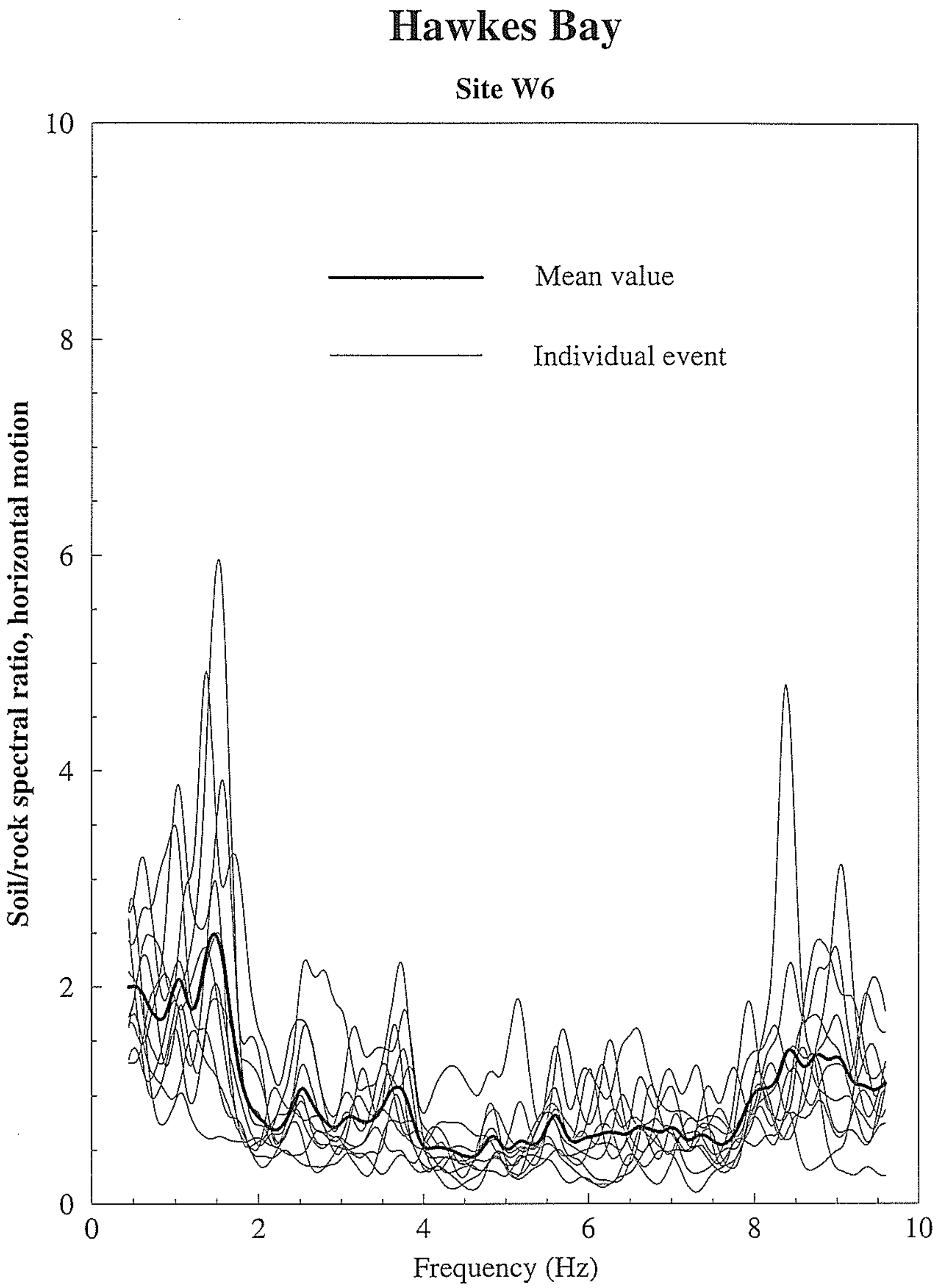

Figure E–10 : Soil/Rock spectral ratios at Clive River, State Highway 2

Hawkes Bay

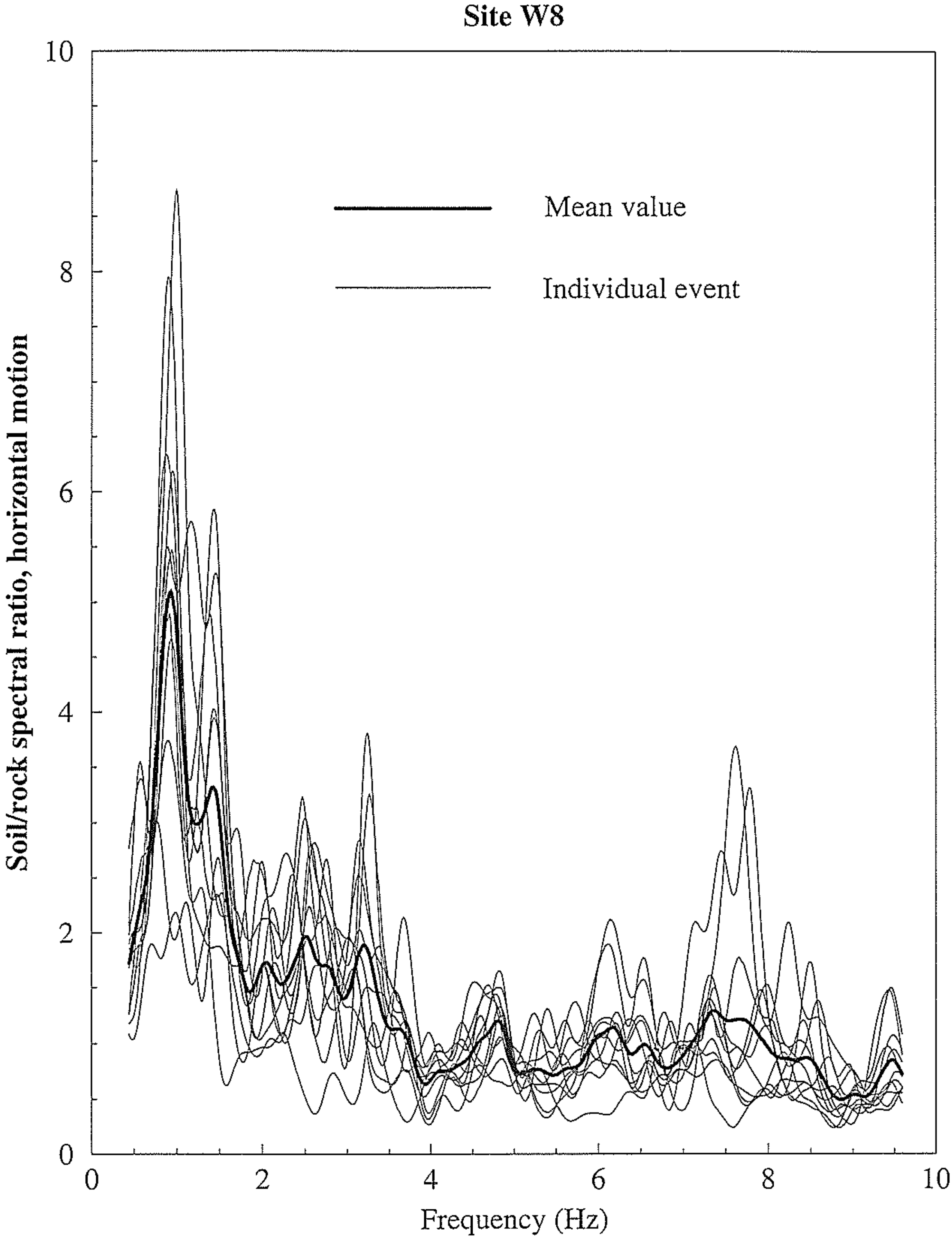

Figure E–11 : Soil/Rock spectral ratios at Napier CC Works Depot

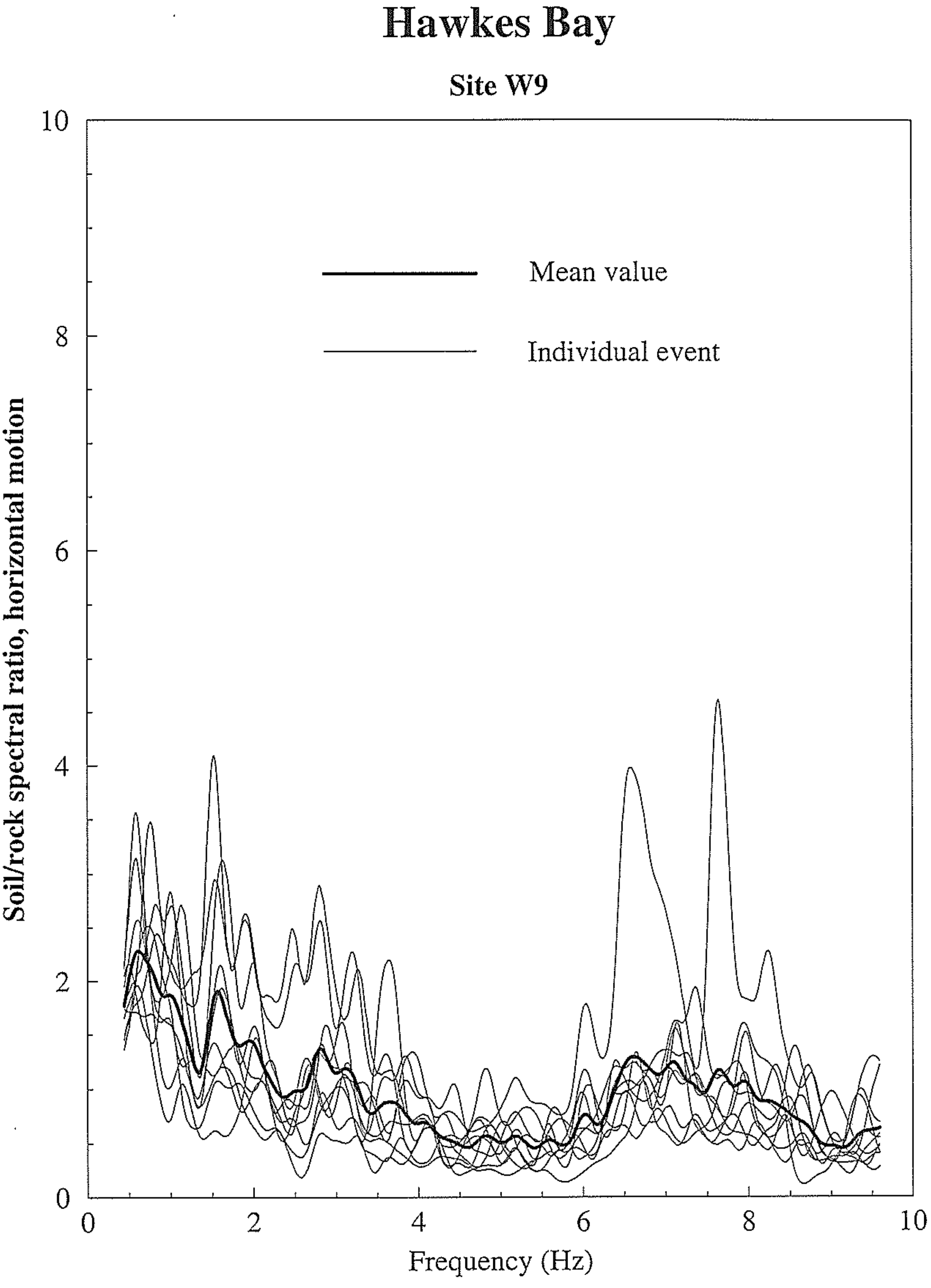

Figure E–12 : Soil/Rock spectral ratios at Perfume Point

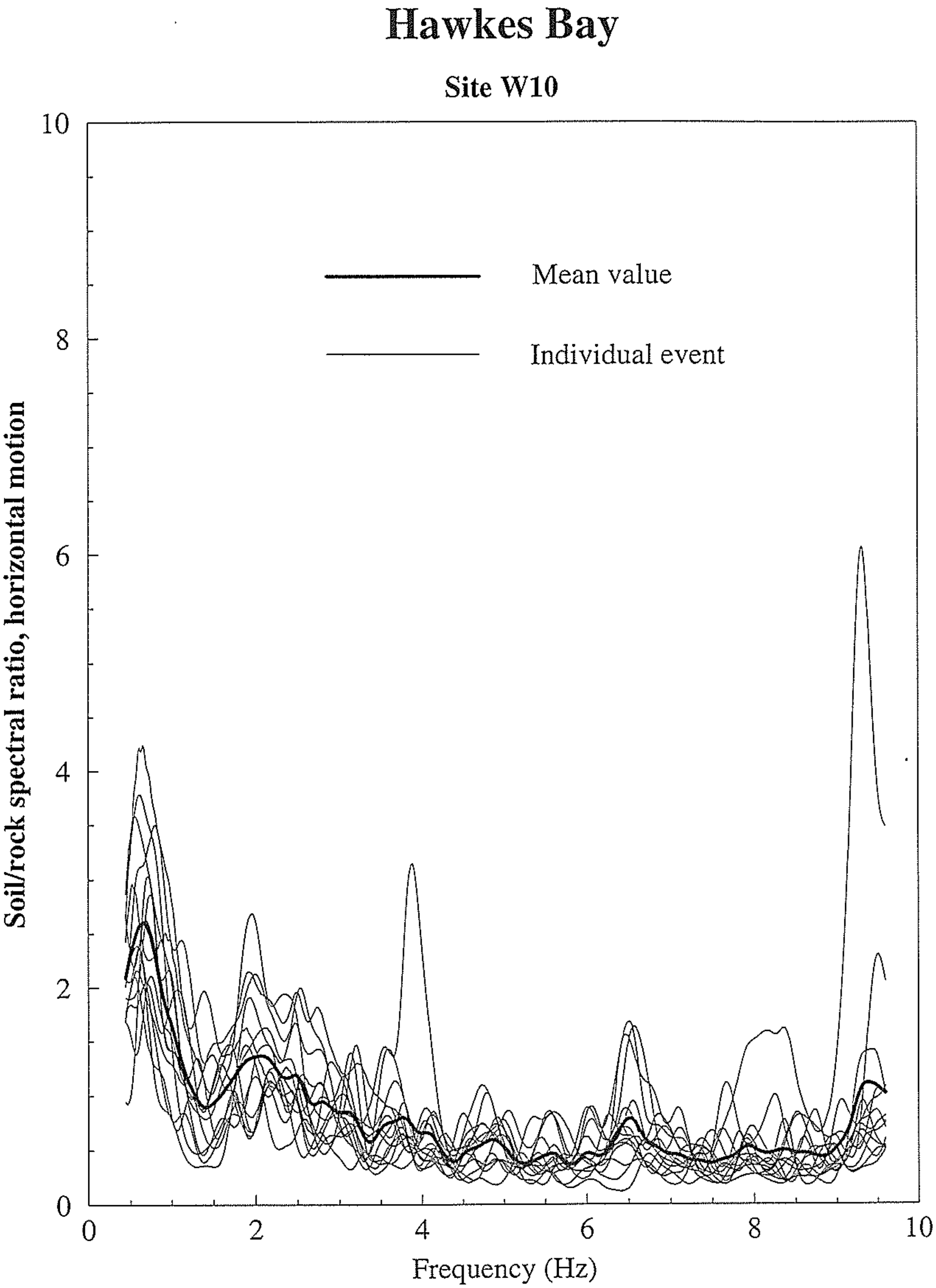

Figure E–13 : Soil/Rock spectral ratios at Westshore Domain

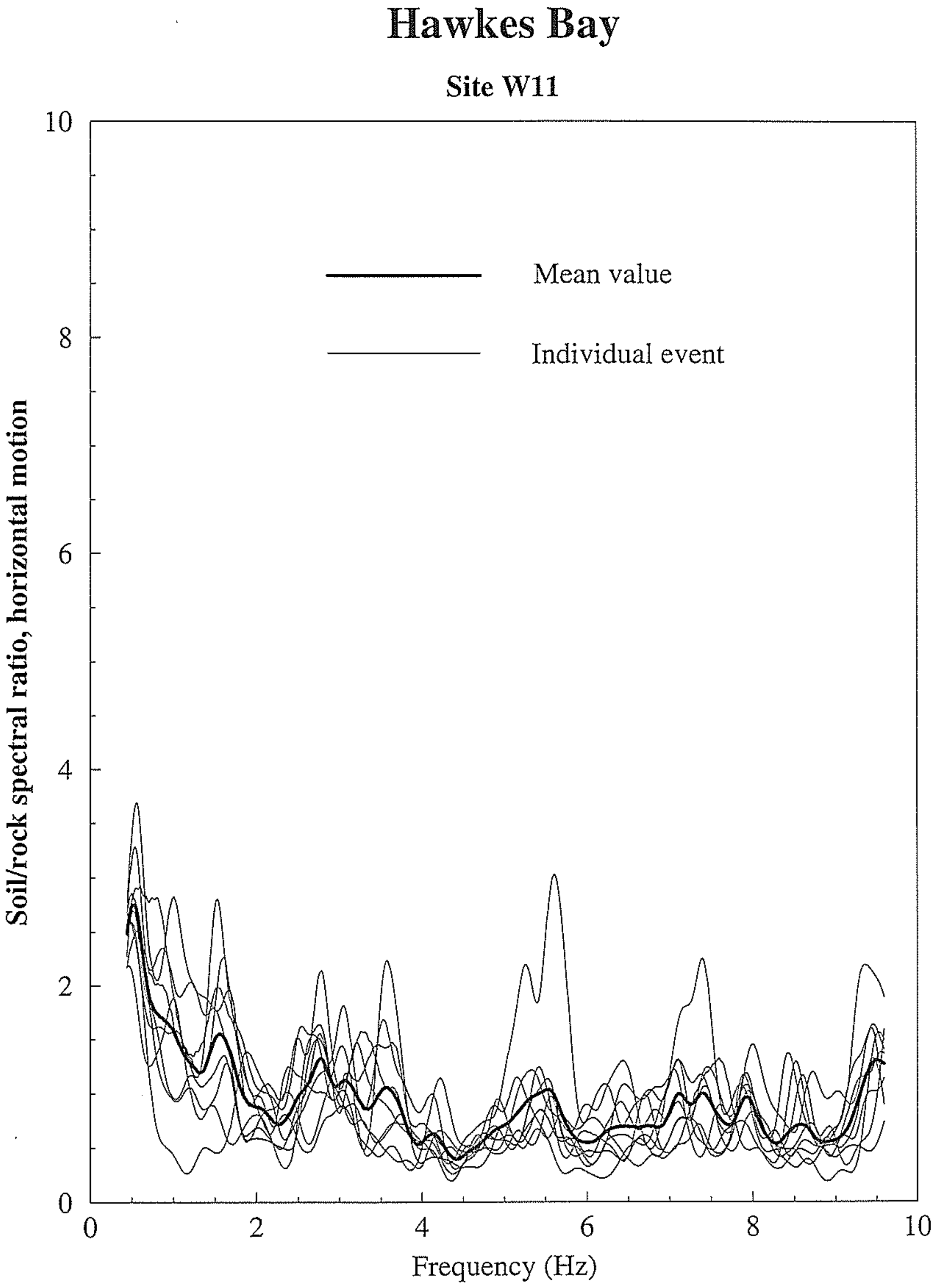

Figure E–14 : Soil/Rock spectral ratios at Napier Airport

APPENDIX F

ACCELEROGRAPH SITE RECORDS

HAWKE'S BAY REGIONAL COUNCIL
EARTHQUAKE HAZARD ANALYSIS PROGRAM
STAGE III

ACCELEROGRAPH SITE RECORDS

SUMMARY

The Institute of Geological and Nuclear Sciences operates an accelerograph network throughout New Zealand, and several of the instruments are permanently deployed in the Hawke's Bay area. By analyzing the data sets obtained from these instruments it is possible to further refine the ground shaking hazard and identify areas where the amplification of ground shaking has occurred during historical (post-1940) earthquakes.

Topographic sites (*i.e.* sites where the topography may cause amplification of seismic shaking) have statistically significantly larger Nakamura ratios in all but the 0.1-0.5s band when compared with non-topographic sites. In other words topographic sites will amplify strong ground shaking in the short period response spectra.

Rock sites with more than 3.0 metres of layered soils have statistically significantly higher values than rock sites with more than 3.0 metres of uniform soil, in the three longer period bands.

Soft sites usually have statistically significant lower values for their Nakamura ratios than others in their class in the 0.1-0.5s band, and statistically significant higher values in the other period bands.

The accelerograph data available from these past earthquakes confirms the resonant frequencies of sites identified through the Nakamura and weak motion studies. The strong motion data has also provided better constraints on the value of the soil/rock spectral ratios for the site response units.

1.0 INTRODUCTION

The Institute of Geological and Nuclear Sciences operates an accelerograph network throughout New Zealand, and several of these instruments are permanently deployed in the Hawke's Bay area. By analyzing the data sets obtained from these instruments it is possible to further refine the ground shaking hazard and identify areas where the amplification of ground shaking has occurred during historical (post-1940) earthquakes.

The first accelerograph in the Hawkes Bay area was installed in 1966, but multiple sites in the Hastings-Napier area have been in place only since 1989.

2.0 PREVIOUS WORK

One of the uses of accelerograph data is in identifying sites that may be capable of amplifying earthquake motion in moderate-to-strong ground shaking. Characteristics such as site resonance and broad-band amplification are often readily apparent, and examples of both have been noted in many accelerograms from New Zealand sites (McVerry & Sritharan, 1991; Sritharan & McVerry, 1992).

3.0 THIS STUDY

To verify the results of the Nakamura analyses which provide quasi-spectral ratios from ambient noise recordings, and the weak ground motion recordings which provide actual ratios of seismic wave amplitudes between soil sites and the reference rock site, we evaluated previous recordings from moderate magnitude earthquakes which have occurred in the region. The relevant sites and associated instrument types are shown in Table F-1. Accelerograph data is available from Wairoa, Waipawa, Napier, Hastings, and Havelock North.

Table F-1: Accelerograph sites in the Hawke's Bay Region.

Site Location	Instrument type*	Site reference number	Latitude	Longitude
Wairoa Telephone Exchange	M S	096A 225B	39.0358	177.4236
Napier Telecom	I	926A	39.4900	176.9169
Napier Museum	D S	027G 229A	39.4903	176.9189
Napier Hospital	D	015A	39.4911	176.8981
Napier Civil Defence	D	014A	39.5017	176.8755
Hastings Civil Defence	D	029A	39.6475	176.8428
St Lukes School, Havelock North	I	928A	39.6728	176.8800
Waipawa Post Office	M S	032A 235A	39.9444	176.5875
Weber Fire Station	M	035A	40.4028	176.3103

Notes: *Accelerograph recording devices are as follows:
M = MO2A film recorder;
S = Scratch plate (obselete, back-up only);
D = Digital recorder (12-bit resolution);
I = Digital recorder (16-bit resolution).

To enable comparison between accelerograph records, weak motion records and the results obtained from the Nakamura survey the following methodology was used for the accelerograph site records:

1. For all records, the Nakamura ratios for Fourier spectra and 5% damped acceleration response spectra were calculated for each individual horizontal component.

2. For each component, the average Nakamura ratio in a number of period bands was calculated (0.1-0.52; 0.5-1.5s; 1.5-5.0s; 0.4-2.0s). These bands were chosen to correspond to those used by Borcherdt (1994) in his studies of site response factors, in order to permit comparison of the Nakamura ratios and Borcherdt (1994) factors.

Often the 1.5-5.0s and sometimes the 0.4-2.0s bands are truncated at shorter periods, if the high (frequency)-pass filter starts to come in at periods shorter than 5.0s or 2.0s respectively. The filter band is selected on the basis of signal strength to nominal noise levels for various record types, and is often governed by the vertical component. The intention is to guarantee that the Fourier spectrum of *displacement* of the retained record lies above the noise.

3. The geometric mean across all horizontal components for a site was calculated for Nakamura ratios in each period band, by averaging the logarithms of the values from the individual components. The standard deviations of the log ratios were also determined.

4. All sites were classified in terms of the NZ4203:1992 classifications using geological site descriptions provided by Mr N.D. Perrin and where available shear-wave velocities measured by Mr P.R. Barker (see Appendix G).

   The NZ4203:1992 categories are:

   Class A: Rock and stiff soil; "site periods" (i.e. four times shear-wave travel time to "effective" rock) less than 0.15s;

   Class B: Intermediate soils; "site periods" between 0.15s and 0.6s;

   Class C: Soft and flexible soils; "site periods" greater than 0.6s.

   NZS4203:1992 gives depths of various types of soil that can be taken as corresponding to these periods, with the travel-times through various layers able to be added together to estimate the overall period.

Several sub-categories of each of these classes were considered. Rock was subdivided into "soft" or "weak" versus "firm/hard" or "strong", based on Borcherdt classifications and input from Mr N.D. Perrin for New Zealand rocks. Rock sites were also separated out on the basis of depth to rock (i.e. less than 3m of soil over rock, classed as AS or AF/AH for the soft and firm/hard rock categories, from the Class A sites with more than 3m of soil, indicated as AL, for layered, usually followed by S or F/H (e.g. ALS) to indicate the underlying rock types.

Sites associated with steep topography or ridgetop positions were identified as topographic sites, (e.g. ATS for a soft rock topographic site, or ATLS for a Class A site with soil layers and topographic effects over soft rock). Such sites often experience amplified seismic shaking.

Class C sites were subdivided into those that were "soft", "deep only", or "soft and deep". Sites were taken as soft if the average shear-wave velocity to the lesser of "effective rock" or 30m was less than 200m/s. (Borcherdt (1994) classifies sites with average shear-wave velocity to 30m depth of less than 200m/s as soft). "Soft" sites can occur in any of Class A, B, or C. All Class C soft sites fit Borcherdt's soft-class, as their travel time to 30m depth must be at least 0.15s, but Class A and Class B "soft" sites may not meet Borcherdt's criterion. Deep Class C sites are those with "effective rock" at greater than 30m depth; some will be "soft" as well, but many (e.g. deep gravel sites with no soft overlying sediments) are not.

The only subdivisions retained for Class B sites were those that were also "soft" (others were considered).

Each of the retained subdivisions showed statistically significant differences in their average Nakamura ratio with respect to other subdivisions in their Class in at least one of the four period bands for the response spectrum based Nakamura Ratios.

Class A as a whole does not have average Nakamura ratios in any period band that can be taken as unity. The AF/AH subclass fits this criteria in at least three of the four period bands. There were very few AF/AH sites in the data set (e.g. Manapouri Power Station, Te Kuha, Cromwell). Generally AS was taken as the reference rock class.

In this study, we are interested in PGA (peak ground acceleration), which is a short-period measure of the strength of ground shaking. The short-period range presented by Borcherdt (1994) is 0.1-0.5s, where the spectral amplification factors were computed from Fourier spectra. The spectral soil/rock ratios for this period band, and three others are presented in Table F-2, below.

Table F-2: Nakamura ratios calculated from accelerograph records on soft rock sites (Class AS) for selected period bands (the rock reference class).

Period bands (seconds)	0.1-0.5	0.5-1.5	1.5-5.0	0.4-2.0
Nakamura ratios	2.25	1.75	1.51	1.74

Topographic sites have statistically significant, larger ratios in all but the 0.1-0.5s band. In other words topographic sites will amplify strong ground shaking in the intermediate and longer period bands of the response spectra.

ALS sites have statistically significant, higher values than AS sites in the three longer period bands. In other words layered soil sites more than three metres thick will amplify strong ground shaking in the longer period bands. This indicates that the short period response spectra will not be amplified in a statistically significant way.

Soft sites usually have statistically significant, lower values for their Nakamura ratios than others in their class in the 0.1-0.5s band, and statistically significant, higher values in the other period bands.

4.0 RESULTS

4.1 Napier Hospital

In the 0.5-1.5s, 1.5-5.0s and 0.4-2.0s bands the average Nakamura ratio (from response spectra) is near or above the mean for soft rock sites, which are interpreted as indicative of topographic effects. NZS4203:1992 Class A (rock or stiff soil sites associated with topography give Nakamura ratios that are significantly higher than those for soft rock sites unaffected by topography. Napier hospital is somewhat unusual for "topographic" rock sites in that the average ratio in the 0.1-0.5s band is reduced from the average for soft rock without topography. Usually the average is a little greater for "topographic" sites, but not significantly so. Individual Nakamura ratio plots show a trough with values around 1.0 out to about 0.3s period with reasonably high values, about 2.0-5.5, over longer periods.

4.2 Napier Civil Defence

NZS4203:1992 Class C site, soft and deep, with an average shear wave velocity to 30 m depth of less than 200 m/s, and a depth to "effective" bedrock of greater than 30 m.

Like Class C soft and deep sites in general, this site has Nakamura response ratios near 3 in 0.5-1.5s band but ratios are smaller than for class C as a whole or class C deep only sites in the short period band (0.1-0.5s). This site has similar average ratios to Hastings Civil Defence. The ratios are also similar to Napier Hospital, but the transfer functions show stronger motions here than at the Hospital. Nakamura ratios peak above 3 in 0.6-1.0s band, stay at similar values at periods above 1.0s, but have a trough with a value around 1.0 in the 0.4-0.5s band.

4.3 Hastings Civil Defence

Results are generally similar to Napier Civil Defence, but it is marginal whether this site can be classified as a soft site. There is a short period reduction in the Nakamura ratio with respect to class C as a whole but this is not as pronounced as it is for Napier Civil Defence.

4.4 Marewa Telephone Exchange

Although not a current accelerograph site many records were obtained from this site during its operational history. Classified according to NZS4203:1992 as a class C deep site, not soft (much more gravelly than Napier and Hastings Civil Defence sites, with only a thin, very low velocity layer).

Extremely high average Nakamura ratios in 0.1-0.5s band were obtained from the data recorded at this site. These values were greater than 6.0 in the mean 0.1-0.5s ratio averaged across 5 records (10 horizontal components), with peaks well over 10 in most records, at around 0.3s. High amplification values of around 4 were noted at longer periods.

The mean value in the 0.1-0.5s period band is the highest average value in any of the standard period bands (0.1-0.5s, 0.5-1.5s, 1.5-5.0s, 0.4-2.0s) for any New Zealand strong motion site (McVerry and Sritharan, 1991).

4.5 Waipawa

Classified as an NZS4203:1992 Class A site, but with about 10 metres of gravel and sand over Tertiary siltstone. Like those class A sites with soil layers (AL), it shows significantly higher Nakamura ratios than soft rock sites. The average Nakamura ratios for Waipawa are above the mean plus one standard deviation level for soft rock sites in all but the 0.1-0.5s band, and above the mean for AL sites in general.

5.0 REFERENCES

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McVerry, G.H., and Sritharan, S., 1991 : Earthquake site response effects demonstrated by New Zealand strong-motion records. *Proceedings 3rd Pacific Conference on Earthquake Engineering, Auckland, New Zealand Vol 3* 205-216.

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APPENDIX G

GEOTECHNICAL DATA

HAWKE'S BAY REGIONAL COUNCIL
EARTHQUAKE HAZARD ANALYSIS PROGRAM
STAGE III

GEOTECHNICAL DATA

SUMMARY

This appendix describes the sources of geotechnical data used in this report. Geotechnical data has been collected from a variety of sources, including Hawke's Bay Regional Council records, IGNS files, and Barker (1994) as well as being collected specifically for this project (Barker, 1997). This data includes:

- Standard Penetrometer Test (SPT N_{60}) results where available;
- Cone Penetrometer Test (CPT) results; and
- Seismic Cone Penetrometer Test (SCPT) results.

The two reports by Barker are included as part of this Appendix.

The low shear wave velocity measurements indicate the generally weak nature of materials in the fluvial, lagoonal and estuarine systems in the region.

1.0 INTRODUCTION

The degree of ground shaking amplification is in part dependent on the nature and thickness of geological materials at depth. The nature of the these materials can affect the amplitude (severity) of shaking and modify the frequency of shaking, for example, amplifying long period motions, but dampening short period motions, and can increase the duration of the shaking. All of these factors have a significant bearing on the overall performance of buildings during strong earthquake ground shaking. Therefore, the subsurface geology of the region was considered when assigning geological units to a site response classes.

Subsurface data from exploratory boring logs (e.g. Ota *et al*, 1989), well logs (Dravid & Brown, 1996), seismic CPT soundings and geophysical surveys were used to assess the distribution and thickness of Quaternary sediments, and establish shear wave velocity profiles for the units. Data sources included primarily the well log data base from HBRC, IGNS files, and logs of borings and soundings from previous studies (relevant data from Barker, 1994 is presented at the end of this appendix).

To supplement the existing data, a series of seismic CPT probes was completed. The results of this investigation are included at the end of this appendix. The methodology for this technique is described fully in Barker and Stephenson (1991). These probes provide information on the stratigraphy, texture and shear wave velocity profile of a site, which is then used in assigning a geological unit to a site response class.

2.0 SUBSURFACE GEOLOGY

The fluvial sediments of the Heretaunga plains (units f2, f3, f4, f5, and f6), consist of interfingered layers and lenses of sand, silt and gravel. The fine grained components of these deposits are generally soft with low blow counts (SPT N_{60}-values < 20 blows per 300 mm) and low shear wave velocities (generally < 200 ms^{-1}), while the gravels are typically harder and difficult to penetrate (SPT N_{60}-values > 50 blows per 300 mm). Due to the proximity of the Heretaunga plains to the coast these units are interlayered with laterally extensive deposits of marine silt and clay, which are also soft and weak with low SPT N_{60} blow count values (< 20 blows per 300 mm) and low shear wave velocities (generally < 200 ms^{-1}).

The lagoonal and estuarine deposits in the vicinity of Napier appear to form a shallow veneer of soft sediments which overlie the interlayered fluvial deposits of the Heretaunga plains. They are in-turn locally overlain by coarse sands and gravels of the beach deposit along Marine parade.

3.0 SHEAR WAVE VELOCITIES

The range of shear wave velocity measurements (Barker, 1997 (at end of this appendix); and Melhuish and Bannister, 1995) for three of the Quaternary geological map units are summarized below:

Geological Unit	Shear Wave Velocity Ranges (m/s)
L1 - Lagoonal deposits reclaimed	80-140
L2 - Ahuriri Lagoon	110-170
F5 - Fluvial Heretaunga Plains	70-230

These values indicate the generally weak nature of materials in both the fluvial and lagoonal estuarine systems in the region. However, the presence of local gravel layers within the section of silt and sand causes higher shear wave velocity values. While the fine grained layers have typical shear wave velocity values of less than 160 m/s, the gravel layers have values of up to 260 m/s (Barker, 1997; at end of this appendix).

In addition to the characteristics of the shallow sediments described above, the analysis requires an estimate of the shear wave velocity of the underlying bedrock in the region. This value is used to modify the attenuation relationship used to calculate ground motions. It is also used as the rock reference value to calculate ratios between response at soil sites and rock sites. The bedrock shear wave velocity value used is 650 m/s (Melhuish and Banister, 1995).

At Wairoa sub-surface investigations (Ota *et al*, 1989) show up to 30 metres of recent (post-glacial) fine sands deposited in an estuarine environment. Geotechnical data for the estuarine sediments at Wairoa gives a low shear wave velocity for the upper 30 metres of sediment (in the order of 130-250 ms^{-1}). The same bedrock shear wave velocity value used for the Heretaunga Plains is also used here (i.e. 650 m/s; Melhuish & Bannister, 1995).

4.0 REFERENCES

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A Report on Cone Penetrometer and
Seismic Cone Penetrometer Testing
at selected sites in lower North Island

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April 1994

Contents

3. Equipment and Methods

3.1 Cone Penetration Test

The equipment and methods have been fully described in Stephenson and Barker (1989).

3.2 Seismic Cone Penetration Test

The equipment and methods have been fully described in Barker and Stephenson (1991) and only a brief outline is given here.

The seismic cone is attached to a standard CPT thrust rod and is pushed down the hole made by the CPT cone. A hammer blow at the surface generates a downward propagating horizontally polarised shear wave which is detected by a miniature geophone in the cone. The arrival is logged on a laptop personal computer for later processing. The process of generating and recording is repeated at 0.5m intervals.

3.3 Core Sampling

The methods used have been described by Thomas and Barker (1974). Hollow-stem augers, with an inside diameter of 85mm, were used to simultaneously advance the drill hole and take "undisturbed" core samples. The samples for University of Auckland were taken in 75mm dia. thin-wall tubes and those for sonic testing were taken in 60mm dia. ring sampler.

1. Introduction

A series of cone Penetrometer and seismic cone Penetrometer probes to help characterise strong-motion earthquake recorder sites was undertaken at the request of the Institute of Geological and Nuclear Sciences Ltd by Landcare Research N Z Ltd and Barker Consulting.

2. Outline of Work

A series of 10 cone Penetrometer and 5 seismic cone Penetrometer probes was undertaken at the following locations:

1	Telephone Exchange, Levin	+ CPT
2	Post Office, Wanganui	+ CPT
3	Pulp Mill,Karioi	+ CPT
4	Grey Street, Gisborne	+ CPT and SCPT
5	Queen Street, Wairoa	+ CPT and SCPT
6	Nelson Park, Napier	+ CPT and SCPT
7	Kennedy Park, Napier	+ CPT and SCPT
8	Napier City Council Works Depot	+ CPT and SCPT
9	Napier Sailing Club, Ahuriri	+ CPT
10	District Council, Waipawa	+ CPT

Testing of the site near the recorder at Martinbrough was considered until investigation revealed that dense gravels are very close to the surface. As the Penetrometer is not suited for these materials, no testing was done. Probing at the Civil Defence H.Q. in Hastings was also considered. Drilling records indicated about 20m of sediments overlies gravels that are part of an aquifer under pressure. Because of the high risk of puncturing the aquifer no tests were done at this site.

At the Gisborne and Wairoa sites "undisturbed" core samples were taken for specialist testing by Dr M Pender, Engineering School, University of Auckland and at the suggestion of Dr S Read, IGNS, for sonic velocity tests by Mr T Mumme,IGNS.

4. Results

4.1 Telephone Exchange, Levin

The probe site was located in a yard next to the exchange building Fig. 1. The surface was compacted gravel. A pilot hole was drilled to 0.5m where probing commenced. Refusal was reached at 1.3m when dense gravels were encountered. A plot of point resistance is shown in Fig. 2. Attempts to drill through the gravels were unsuccessful because of their dense nature.

4.2 Post Office, Wanganui

The probe site was in an old garden plot along the access driveway to the rear of the building Fig. 3. On the first attempt to probe, refusal to penetration, because of high point resistance was met at 0.9m. A further attempt was made at another site about 1m away. Refusal was met again at 0.9m. The high resistant layer was then drilled through and probing restarted at 1.4m only to met another high resistance layer at 1.7m. The was then drilled to 2.7m and probing continued. Another high resistant layer was encountered at 2.9m. It was decided to cease for probing because of the lack of data being obtained and the high probability of the similar ground conditions being met. The cuttings coming up the auger flights indicated the materials being drilled were interbeded silts and sands. The ground water was at 0.9m. Results of point resistance are shown in Fig.4.

4.3 Pulp Mill, Karioi

This probe was located on a grassed area adjacent to the main administration building. Refusal to penetration because of high point resistance was at 3.0m when gravels were encountered. Point resistance and friction ratio plots are shown in Fig.5. A plot of inferred material textures is given in Fig. 6. Information from the site investigations for the Tangiwai Rail Bridge indicated a considerable thicknesses of very dense volcanic gravels and boulders (Northey, pers comm).

4.4 Grey Street, Gisborne

4.4.1 Cone penetration test

This site was in a vacant section next to the old gas works, Fig.7. The cone penetration test reached 23.9m before refusal, which was caused by the accumulated side friction rather than high point resistance. Results of point resistance and friction ratio are shown in Fig.8. Between 3.5m and 22m the ground is clayey silts, gradually increasing in strength with depth. The thin high resistant layer at 12m is most likely to be a thin volcanic ash bed. Bore logs from site investigations for the Post Office and T & G Building, a bit further along Grey Street, identified a thin layer of pumiceous ash at a similar depth (Read, pers comm). Below 22m the ground becomes more clayey and slightly stronger. A plot of inferred material textures is shown in Fig.9.

4.4.2 Seismic cone penetration test

The seismic cone was able to be pushed to 24.5m. A plot of the shear-wave arrival times against depth is shown in Fig.10. The shear-wave velocity gradually increases with depth from 98m/sec to 240m/sec. There is also a suggestion of a reflection off the layer at about 24m. Fig.11 shows a plot of this interpretation.

4.4.3 Core sampling

Six 75mm dia. x 700mm long core samples for University of Auckland were taken at the following depths:

1.7 - 2.4m
4.0 - 4.7m
6.1 - 6.8m
7.7 - 8.4m
9.9 - 10.6m
11.4 - 12.1m

Three 60mm dia. x 400mm long cores for IGNS were taken from the following depths:

2.4 - 2.8m
6.8 - 7.2m
10.6 - 11.0m

4.5 Queen Street, Wairoa

4.5.1 Cone penetration test

The probe site was on a section 3 along from the intersection of Queen/Locke Streets and directly opposite the District Council Buildings where and new house was being built, Fig. 12. The Penetrometer reached 31.0m before progress was stopped by the accumulation of side friction. Results of point resistance and friction ratio are shown in Fig. 13. The materials encountered are mainly soft - firm silts with layers of firm - stiff silty clay. A plot of the inferred textures is shown in Fig. 14.

4.5.2 Seismic cone penetration test

During the first attempt a fault in the cable prevented the test from being completed. A second site visit was made several months later after a new cable and other equipment modifications had been made. By that time the house had been completed and there was no access to the original site. A new site about 15m away on an adjacent vacant section was selected. The seismic probe was able to be pushed to 28m. Results of shear-wave arrival time against depth are shown in Fig.15. From 0 - 6.5m the shear-wave velocity is 130m/sec. Between 6.5 and 10.5m there is an increase to 185m/sec. At 10.5m the shear-wave velocity is reduced to 138m/sec and then gradually increases with depth to be 247m/sec at 21m. This interpretation is shown in Fig. 16.

4.5.3 Core sampling

Core samples for University of Auckland were taken from the following depths:

1.5 - 2.2m
4.5 - 5.1m
6.2 - 6.7m
8.3 - 8.9m
10.7 - 11.2m

Core samples for IGNS were taken from the following depths:

5.1 - 5.4m
8.9 - 9.2m
11.2 - 11.5m

4.6 Nelson Park, Napier South

4.6.1 Cone penetration test

This site was on a grassed area next to the Napier City Pipe Band rooms in the park Fig. 17. The results of point resistance and friction ratio, shown in Fig. 18, indicate about 3.5m of soft - firm silt / silty clay overlying dense sands and gravel. Refusal due to high tip resistance was at 5.5m. A plot of the inferred textures is shown in Fig. 19.

4.6.2 Seismic cone penetration test

Results of shear-wave arrival time against depth, shown in Fig.20, indicated the top 4m has a shear-wave velocity of 60m/sec and below that the shear-wave velocity is 238m/sec. A plot of this interpretation is given in Fig.21.

4.7 Kennedy Park, Marewa

4.7.1 Cone penetration test

This site was located in the grounds of the Kennedy Park Motor Camp, Fig. 17, on the boundary parallel to Riverbend Road. Results of point resistance and friction ratio, Fig. 22, indicate about 7.5m of stiff - firm silty sand overlying about 0.8m of sand. From 8.3 m there is about 2m of soft sandy silt directly overlying dense sands and gravel. Refusal, due to high point resistance, was at 10.7m. Fig. 23 shows a plot of the inferred material textures.

4.7.2 Seismic cone penetration test

A plot of the shear-wave arrival times against depth is shown in Fig 24. The interpretation shows an almost constant velocity of 163m/sec, Fig. 25.

4.8 Napier City Council Works Depot, Onekawa

4.8.1 Cone penetration test

This site was located on a small grassed area inside the compound next to the administration building, Fig. 17. Results of point resistance and friction ratio, Fig. 26, indicate that the sediments to 30.2m are multi-layered of variable strength and texture. Probing below this depth was not possible because the friction sleeve became jammed by fine sand. A plot of the inferred textures is shown in Fig. 27.

4.8.2 Seismic cone penetration test

Shear-wave arrival times against depth are plotted in Fig.28. These have been interpreted, Fig.29, as the top 5m of the ground having a shear-wave velocity of 97m/sec, from 5 - 16m a shear-wave velocity of 170m/sec increasing to 194m/sec.

4.9 Napier Sailing Club, Ahuriri

Only a cone penetration test was done at this site which was located in the middle of the boat storage area north of the petrol station on Pandora Road, Fig 17. Results of point resistance and friction ratio, shown in Fig. 30, indicate the top 4m of the ground as gravelly sand (fill?) overlying a thin layer of firm silt then dense sands and gravel. No seismic cone testing was undertaken at this site because of the shallow depth to refusal. Fig. 31 shows a plot of the inferred material texture.

4.10 District Council, Waipawa

Only a cone penetration test was done at this site which was in the middle of a grassed area next to the Central Hawke's Bay District Council offices. Refusal because of high tip resistance occurred at 1.2m. A plot of point resistance is shown in Fig. 32.

5. General Comments

The cone penetrometer was designed principally for use in fine-grained sediments and is not capable of operating through dense gravelly materials. The equipment used for this work has only a 3 tonne thrust capacity and when operating in fine-grained sediments a buildup of side friction on the sounding rods is a frequent reason for being unable to continue penetration. This does not necessarily mean that this technique is inappropriate but that higher capacity might be able to advance further.

The point resistance values shown in the figures are accurate to +/- 400 kPa over 2 Mpa, and to +/- 70 kPa below 2 Mpa. The friction ratio values have an accuracy of +/- 20% of the plotted values when uniform materials are being penetrated, but when the materials change rapidly the accuracy is less because the point can be in one type of material and the friction sleeve in another. The Searle Diagram (Searle, 1979) is used only to provide an indication of material types being encountered. An enhancement of the Searle model for New Zealand conditions would be possible if resources were made available to analyse the data currently held in various databases.

The measured seismic velocities are accurate to +/- 5 m/sec.

Additional analysis to obtain interval velocities would be possible because data from the two geophones, separated by 1 m, has also been recorded.

6. References

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Thomas, R.F. and Barker, P.R. 1974. Simultaneous drilling and sampling using hollow - stem augers. *N Z Engineering, 29.*

7. Acknowledgements

Terry Mumme, IGNS, for his assistance with the field work. Bill Stephenson , IGNS, for his assistance with the preparation of the seismic cone results and helpful comments on this report.

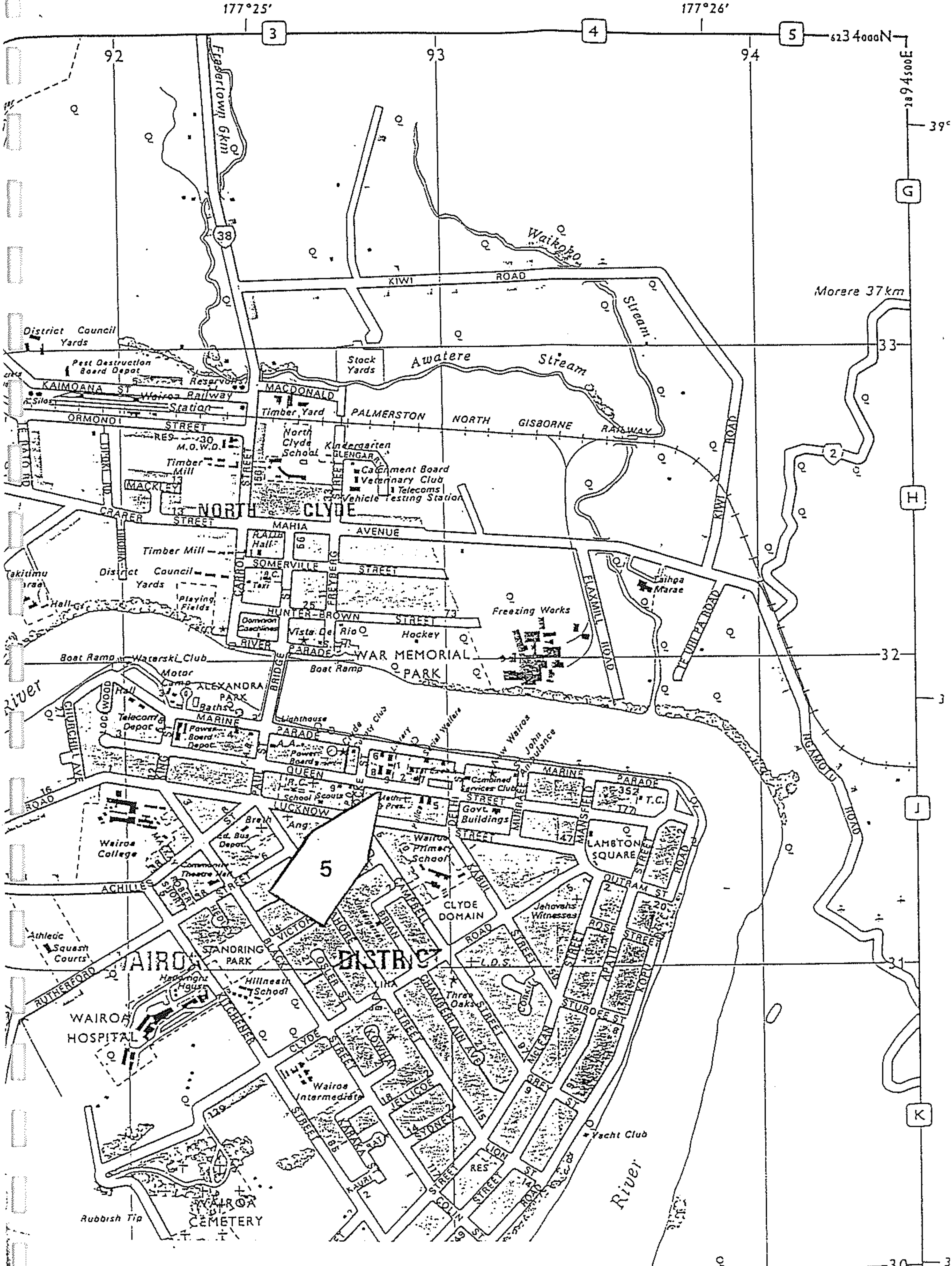


Fig. 12 Map showing location of test site - Wairoa

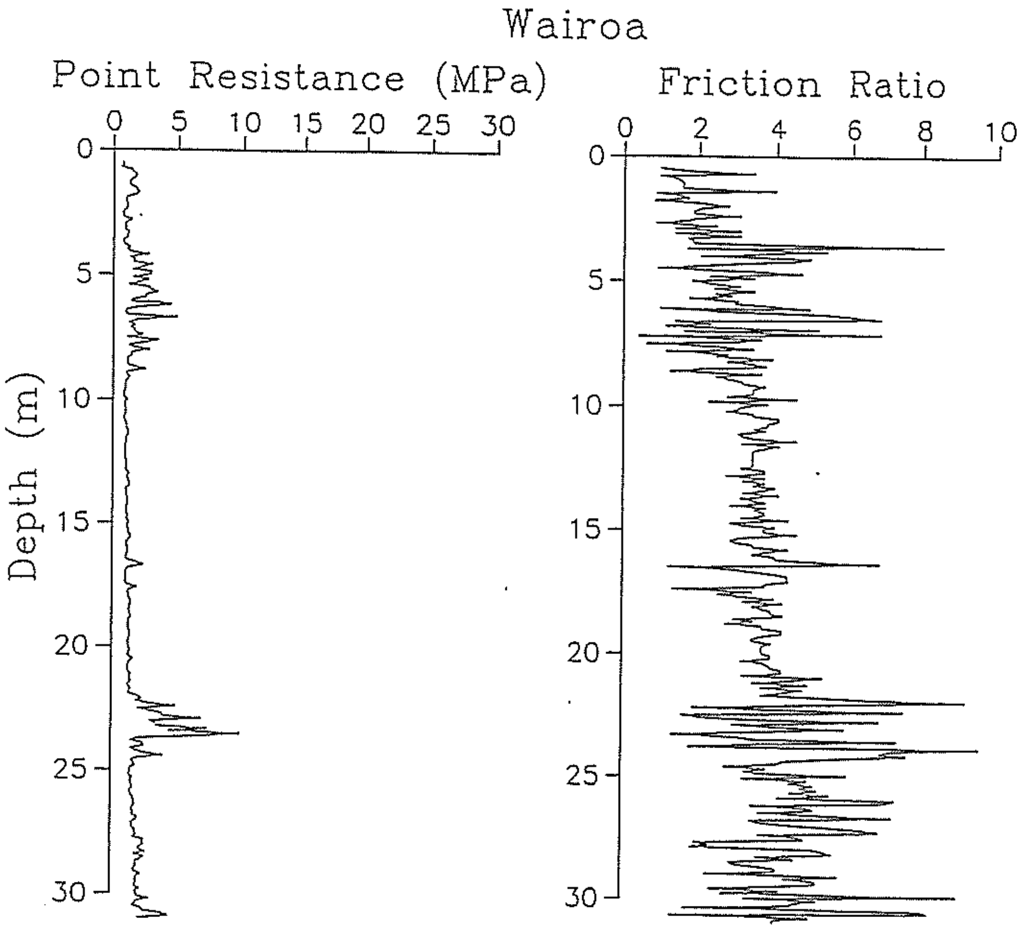


Fig. 13 CPT results - Wairoa

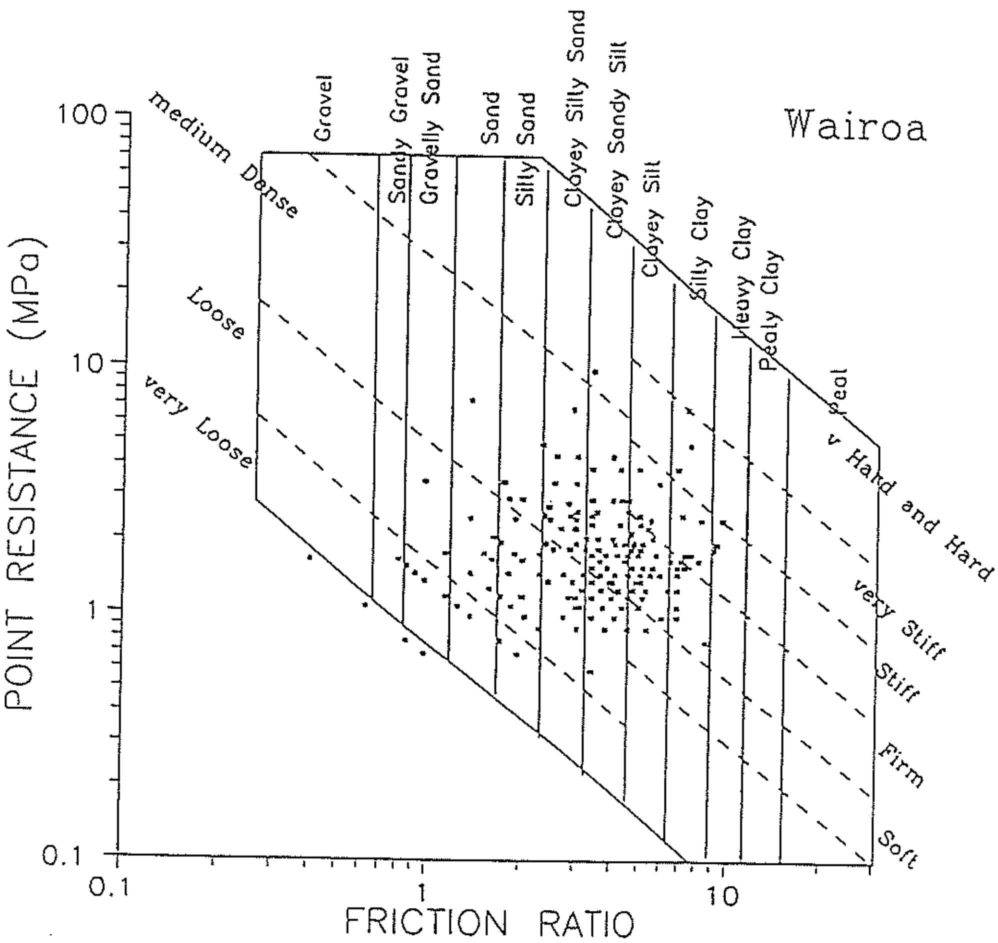


Fig. 14 Inferred texture - Wairoa

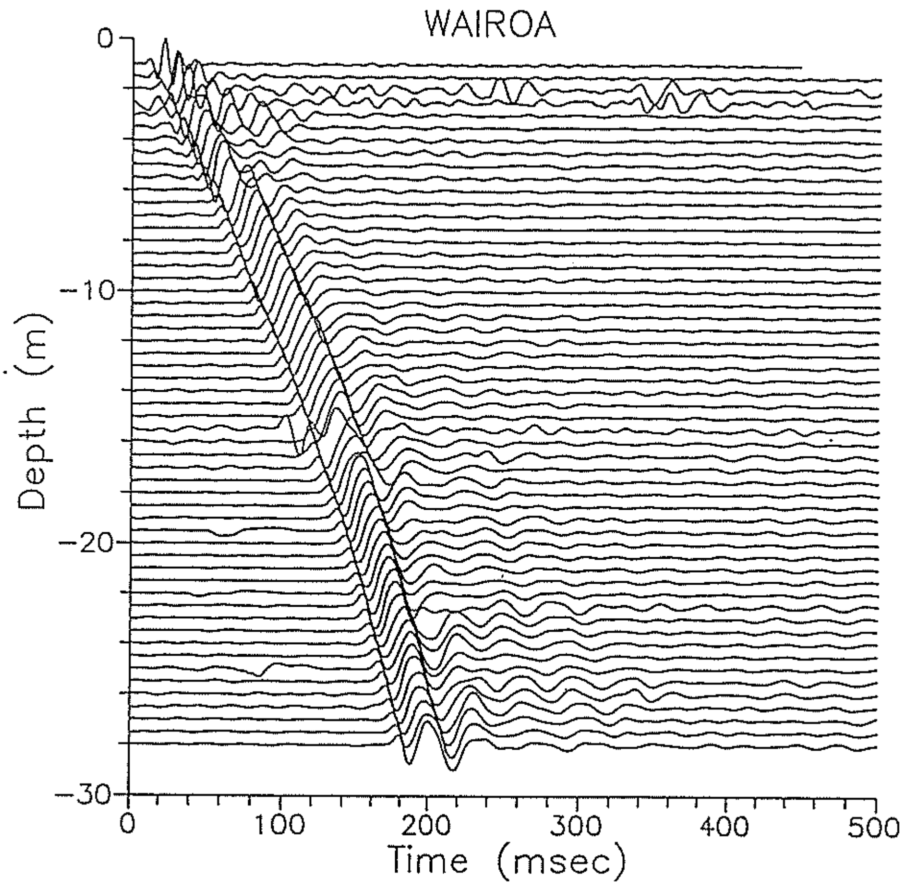


Fig. 15 Seismic CPT results - Wairoa

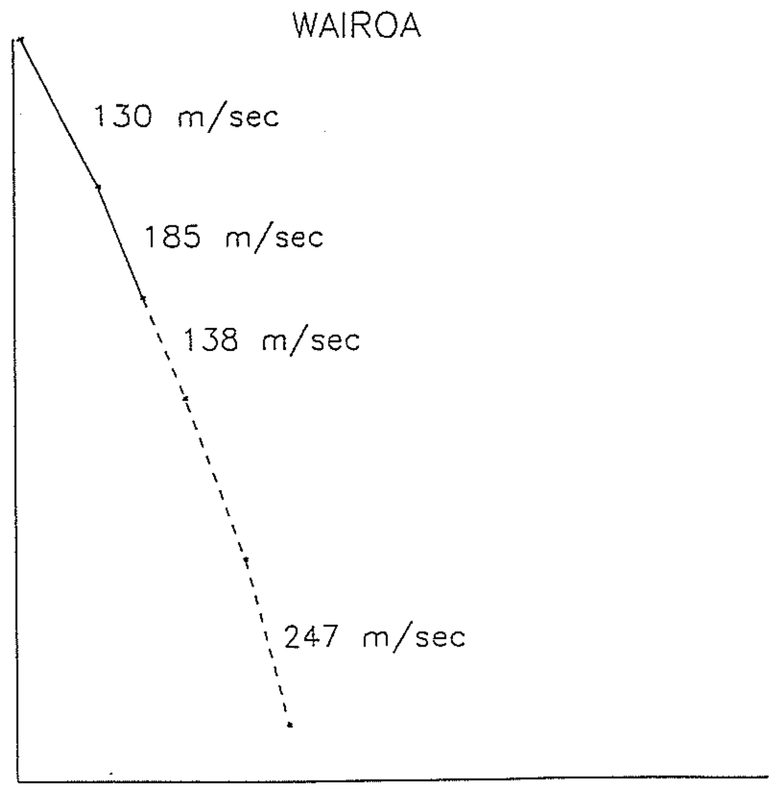


Fig. 16 Interpretation - Wairoa

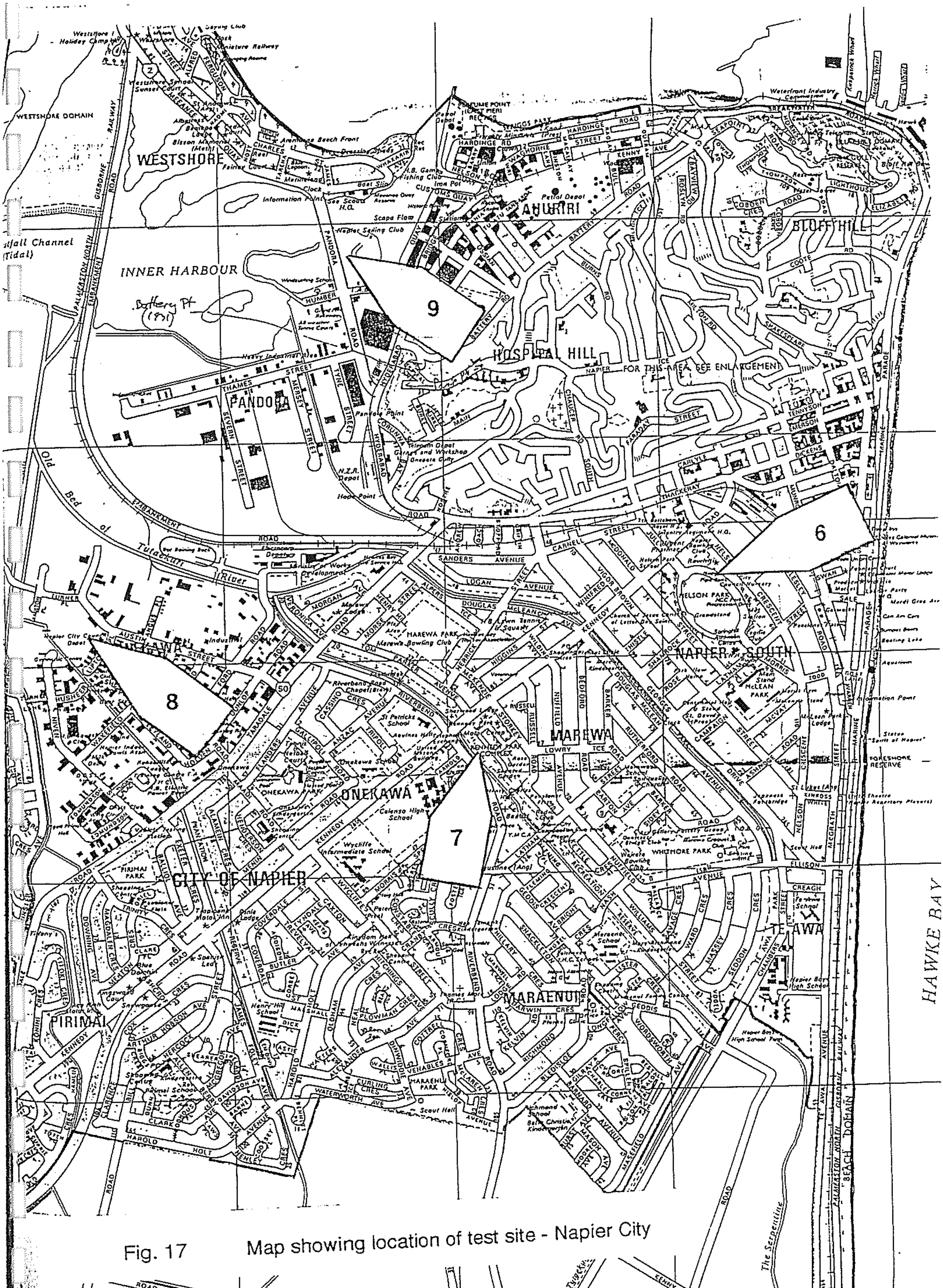


Fig. 17 Map showing location of test site - Napier City

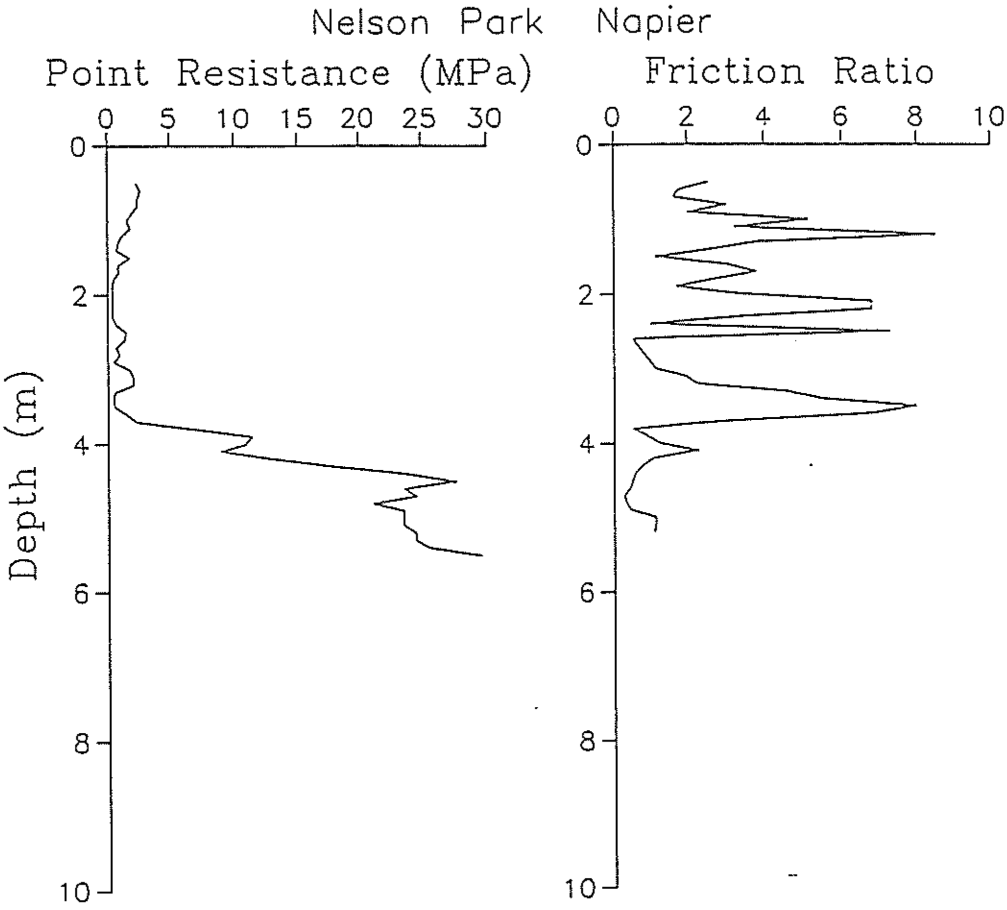


Fig. 18 CPT results - Nelson Park

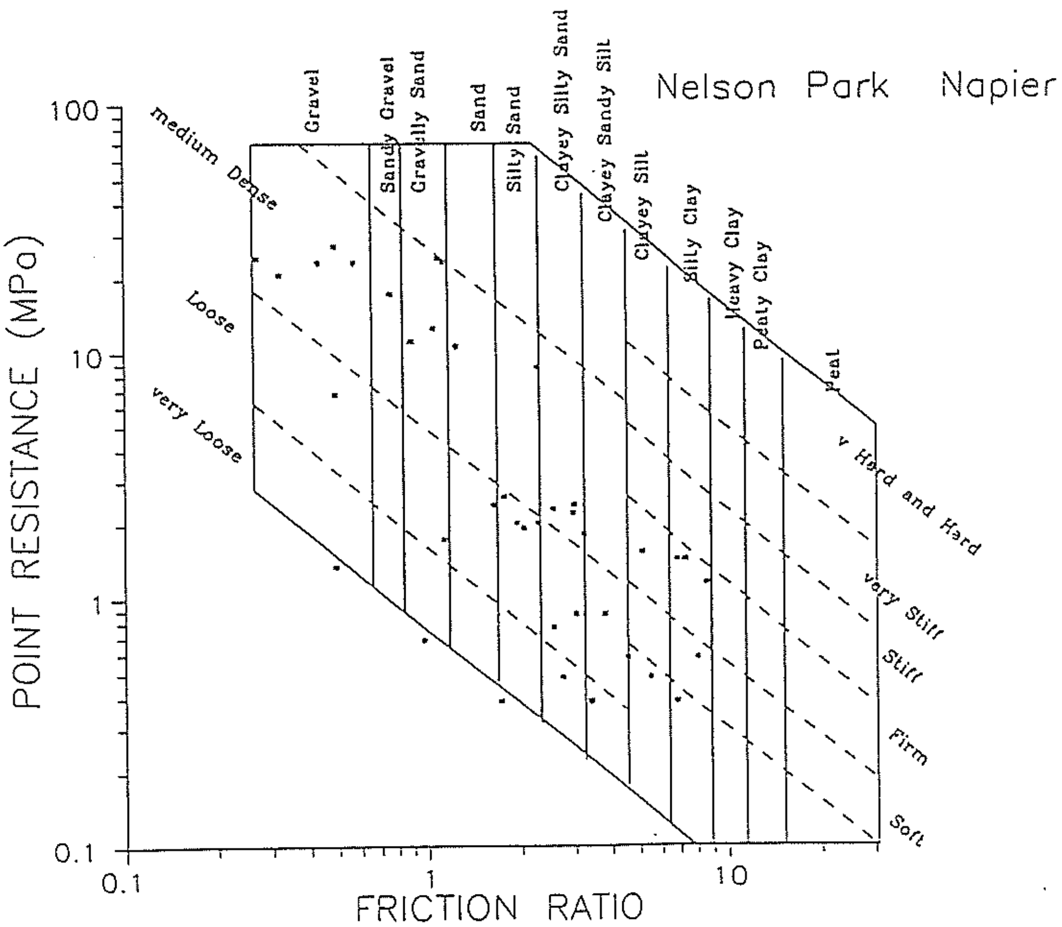


Fig. 19 Inferred texture - Nelson Park

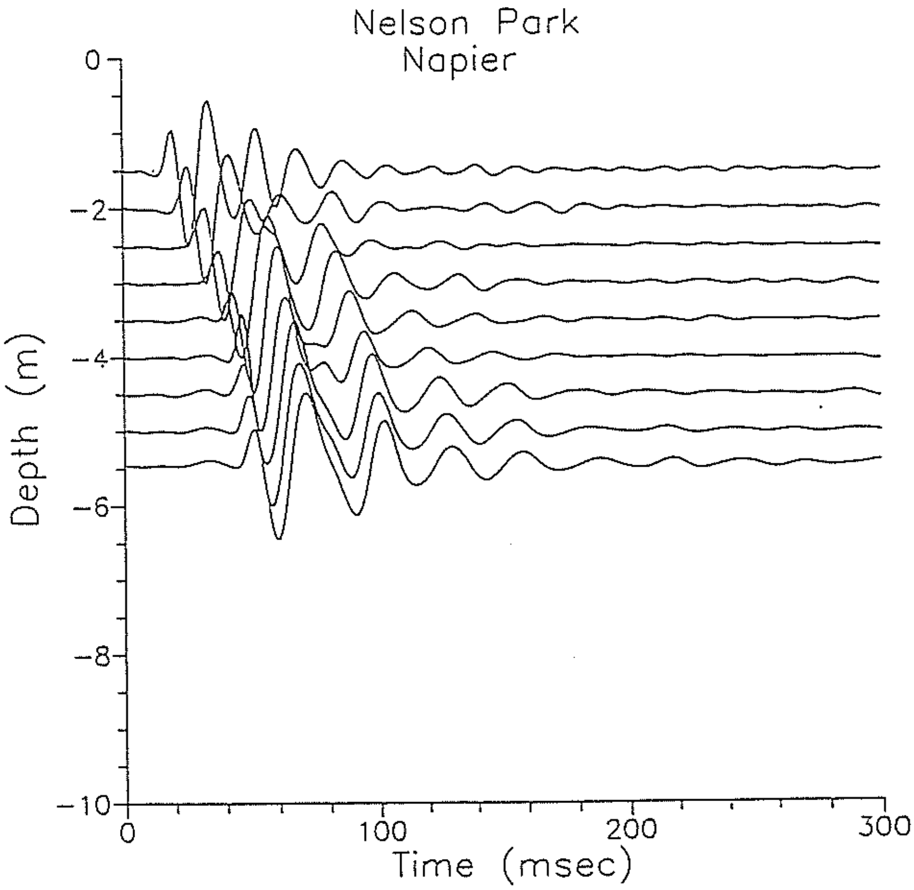


Fig. 20 Seismic CPT results - Nelson Park

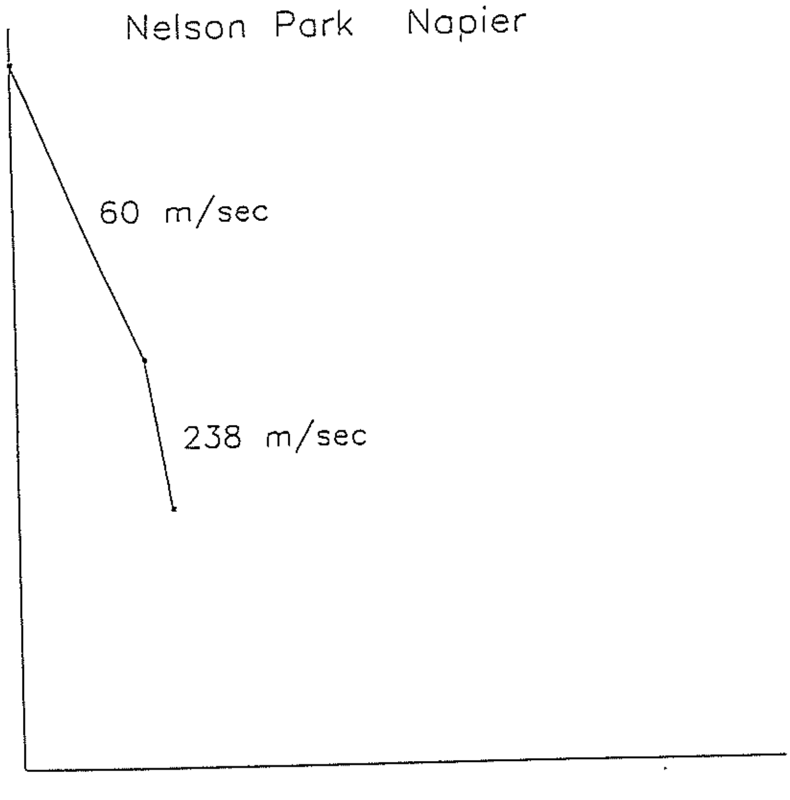


Fig. 21 Interpretation - Nelson Park

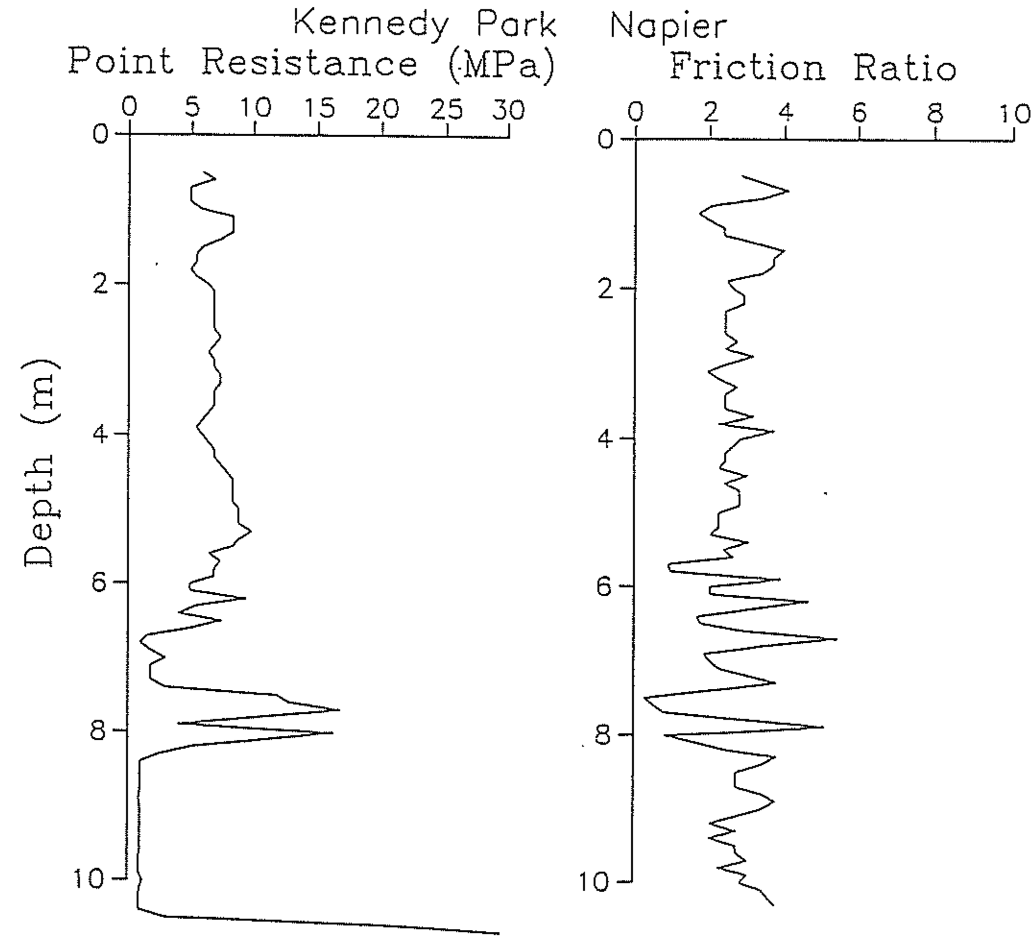


Fig. 22 CPT results - Kennedy Park

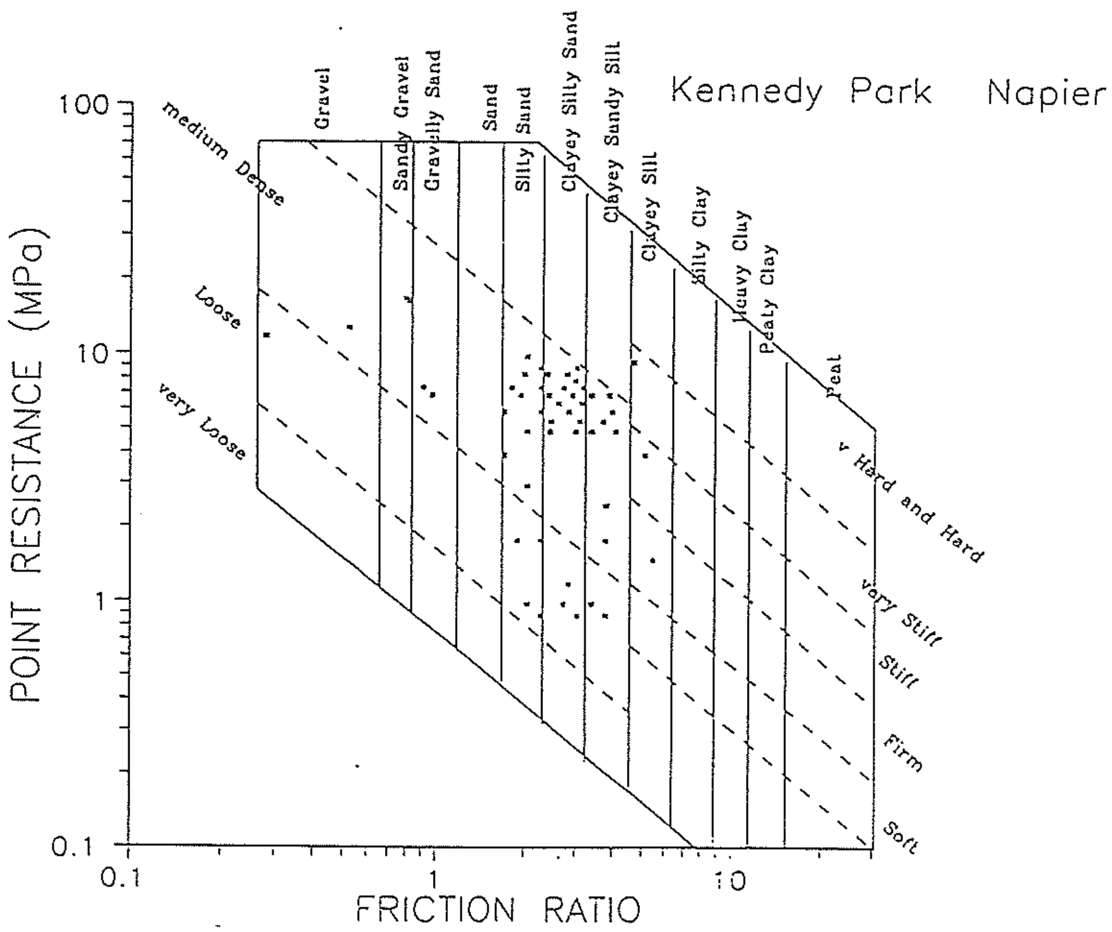


Fig. 23 Inferred texture - Kennedy Park

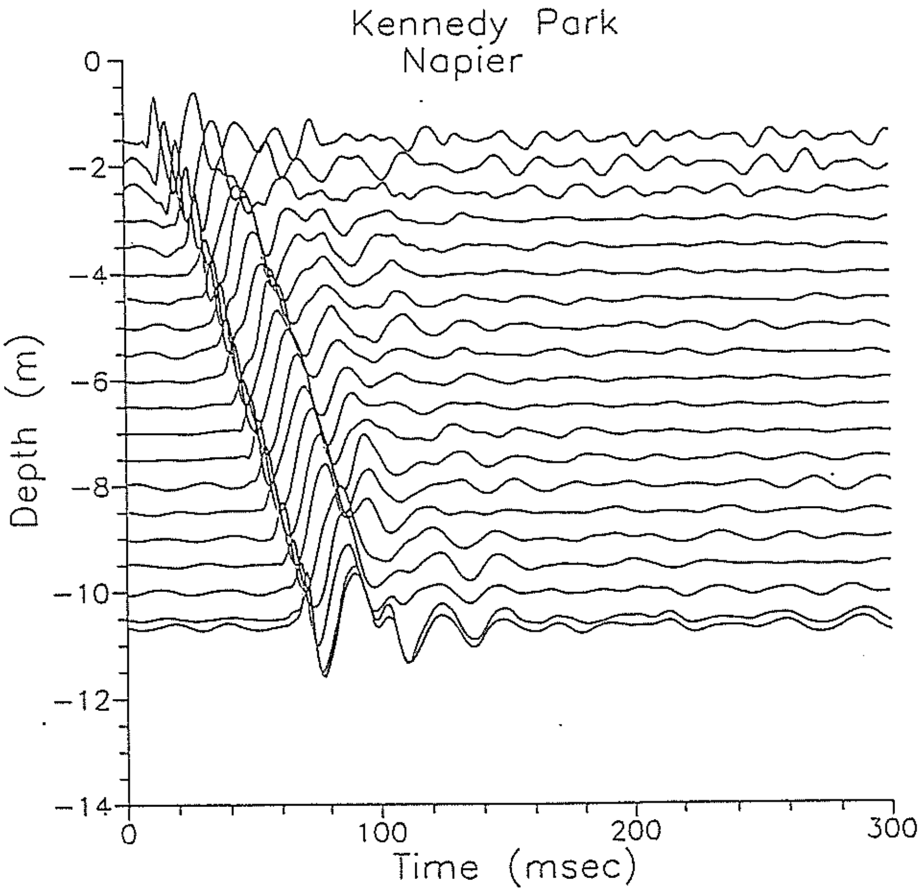


Fig. 24 Seismic CPT results - Kennedy Park

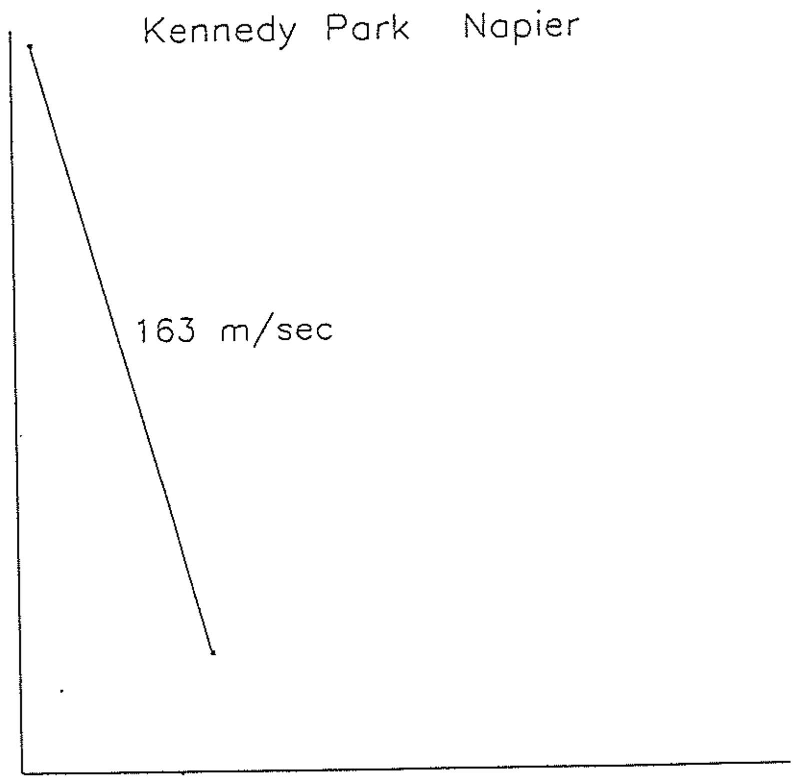


Fig. 25 Interpretation - Kennedy Park

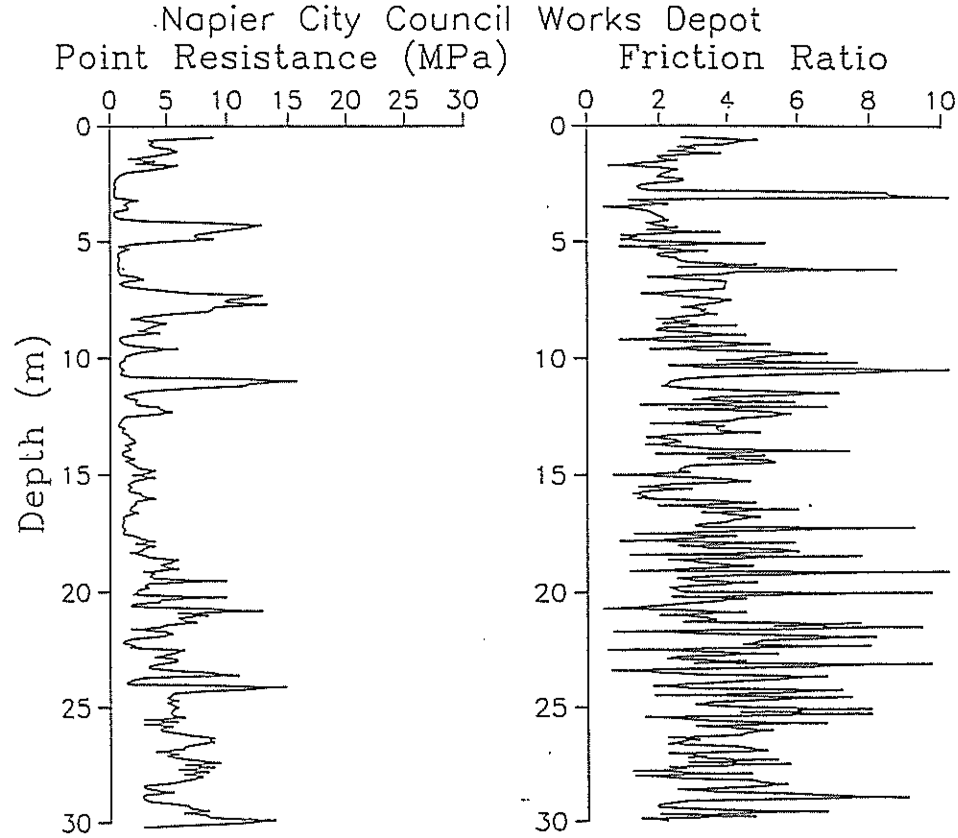


Fig. 26 CPT results - Napier City Council Works Depot

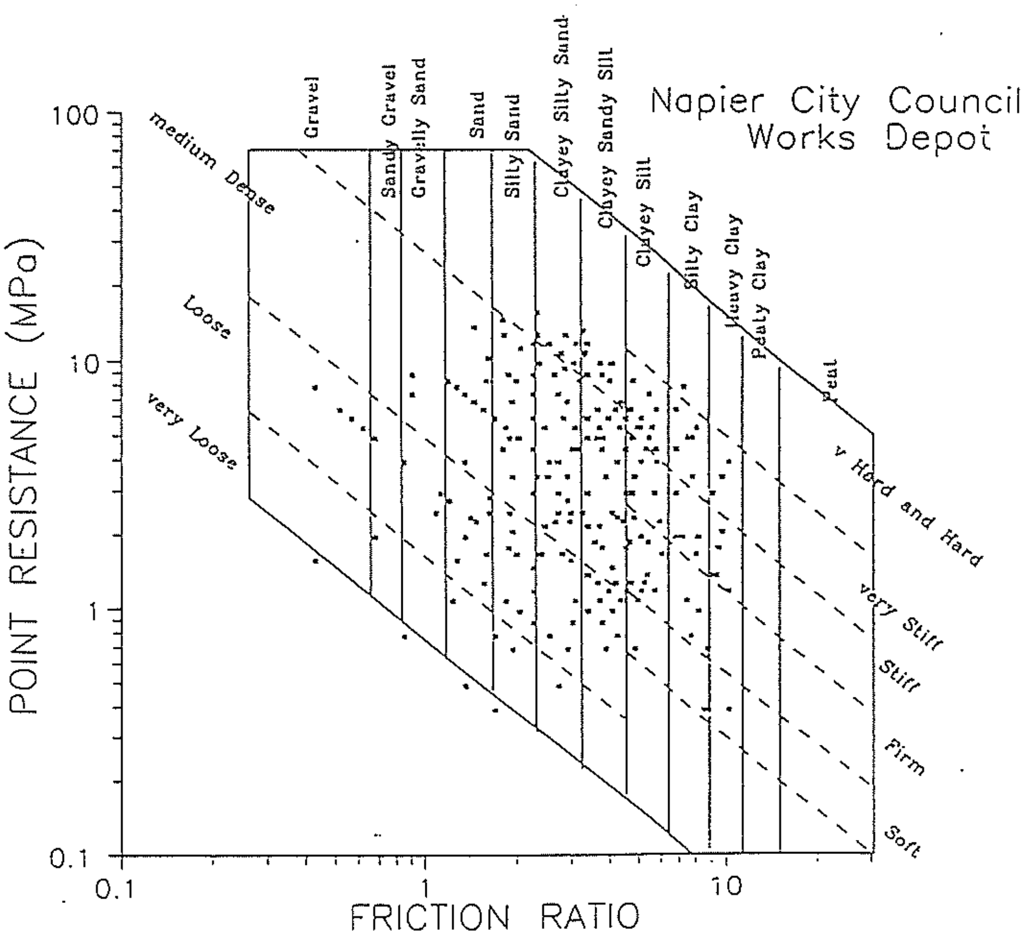


Fig. 27 Inferred texture - Napier City Council Works Depot

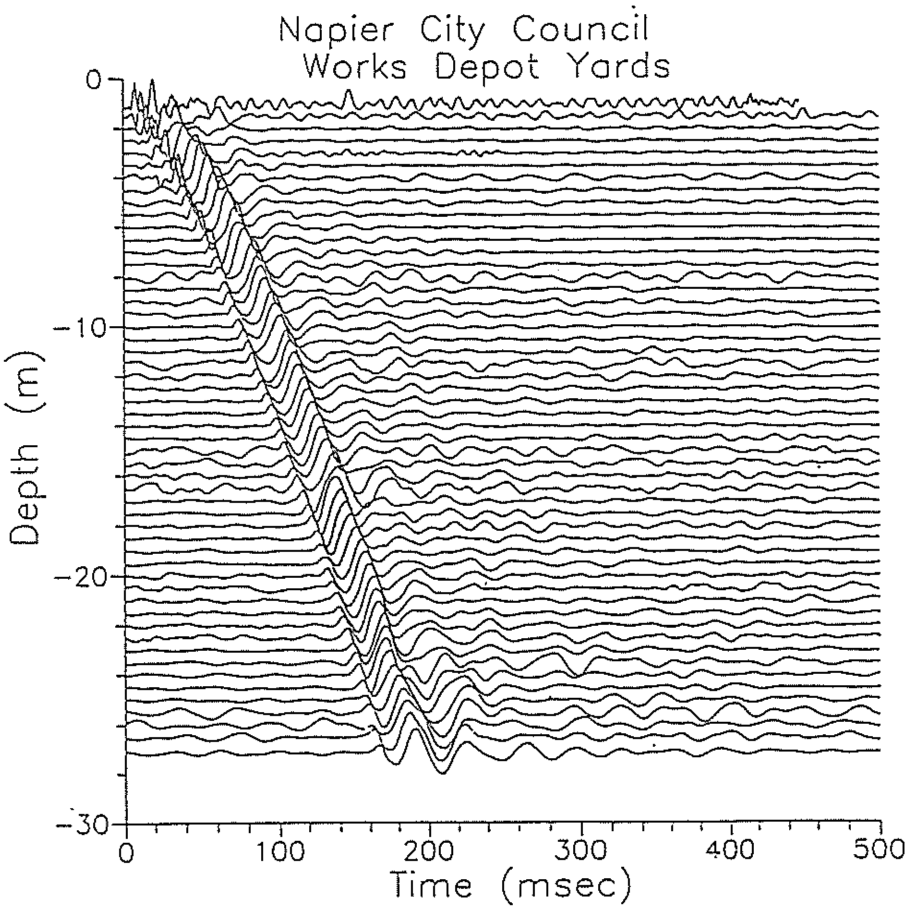


Fig. 28 Seismic CPT results - Napier City Council Works Depot

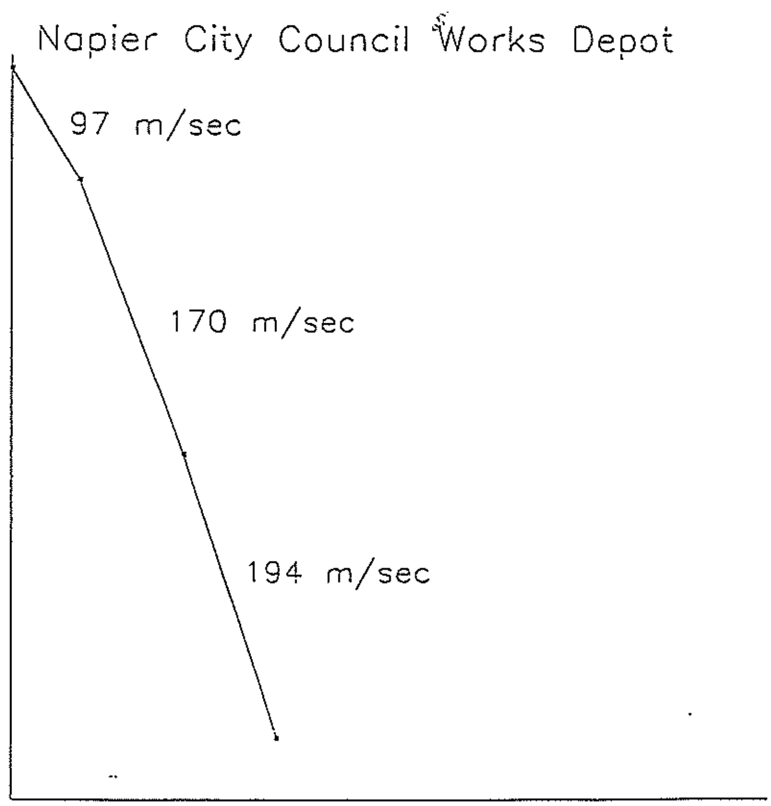


Fig. 29 Interpretation - Napier City Council Works Depot

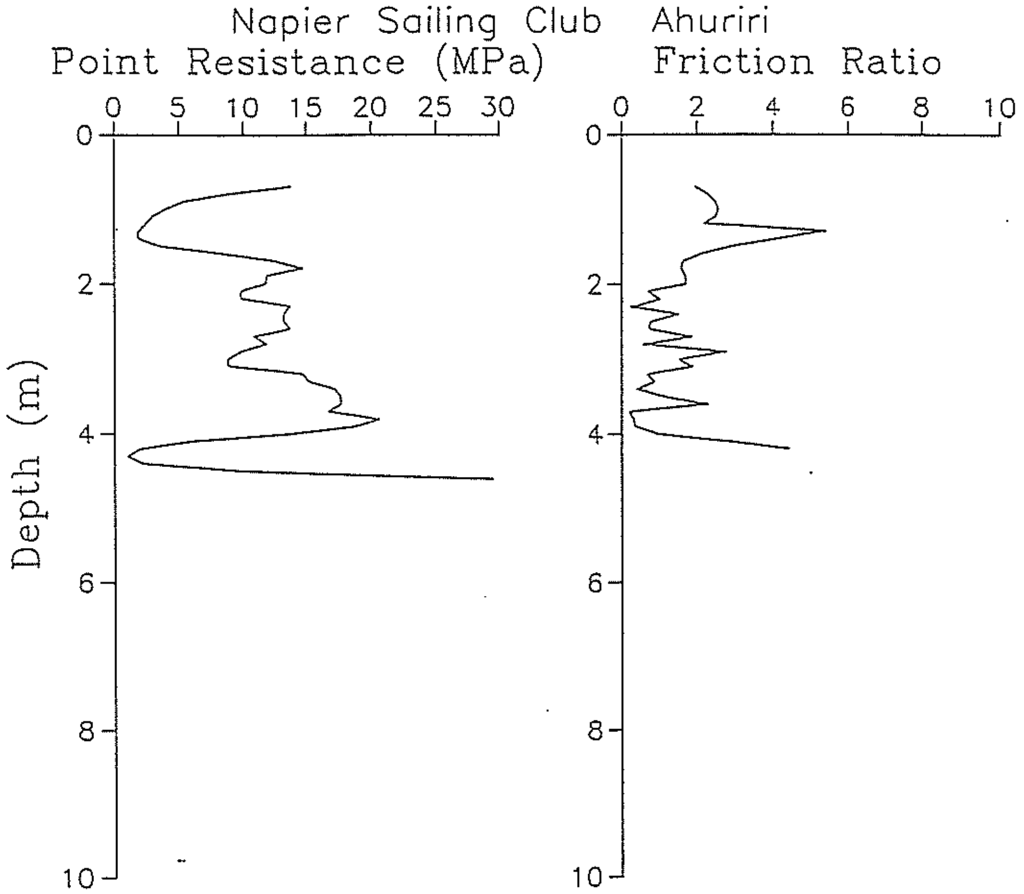


Fig. 30 CPT results - Napier Sailing Club

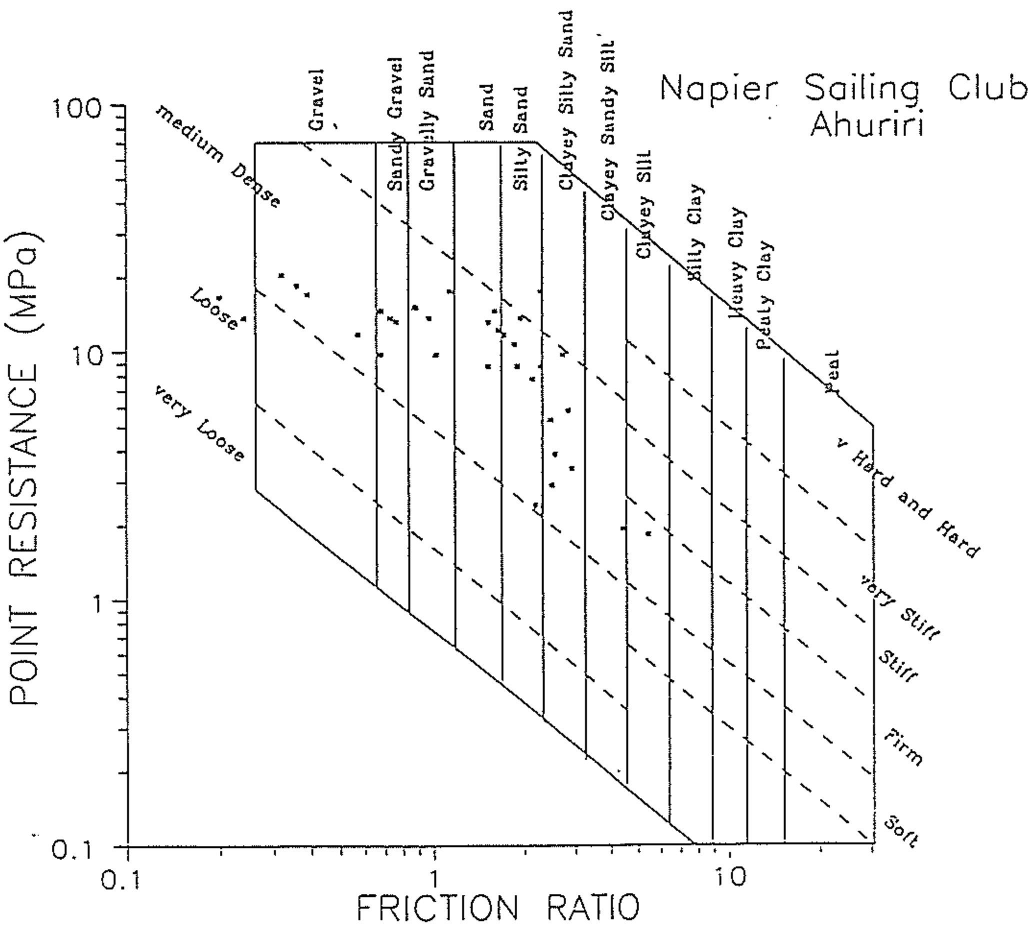


Fig. 31 Inferred texture - Napier Sailing Club

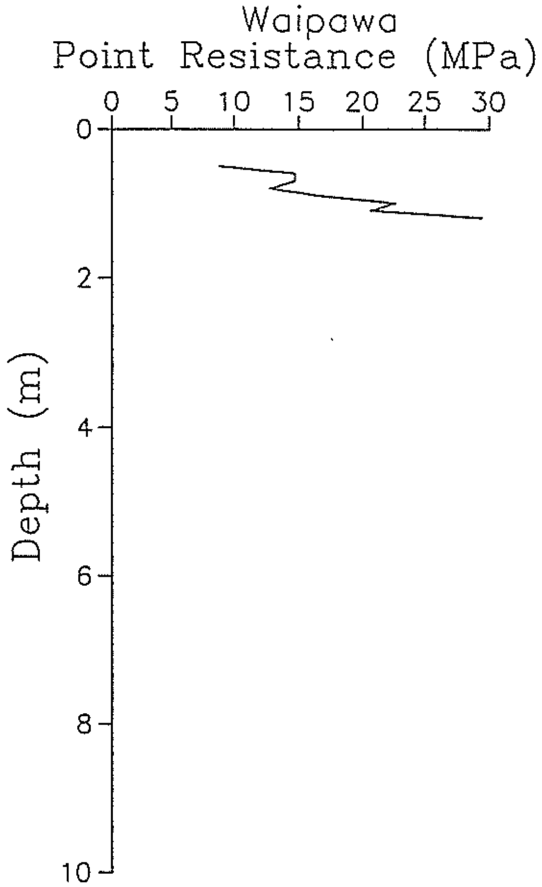
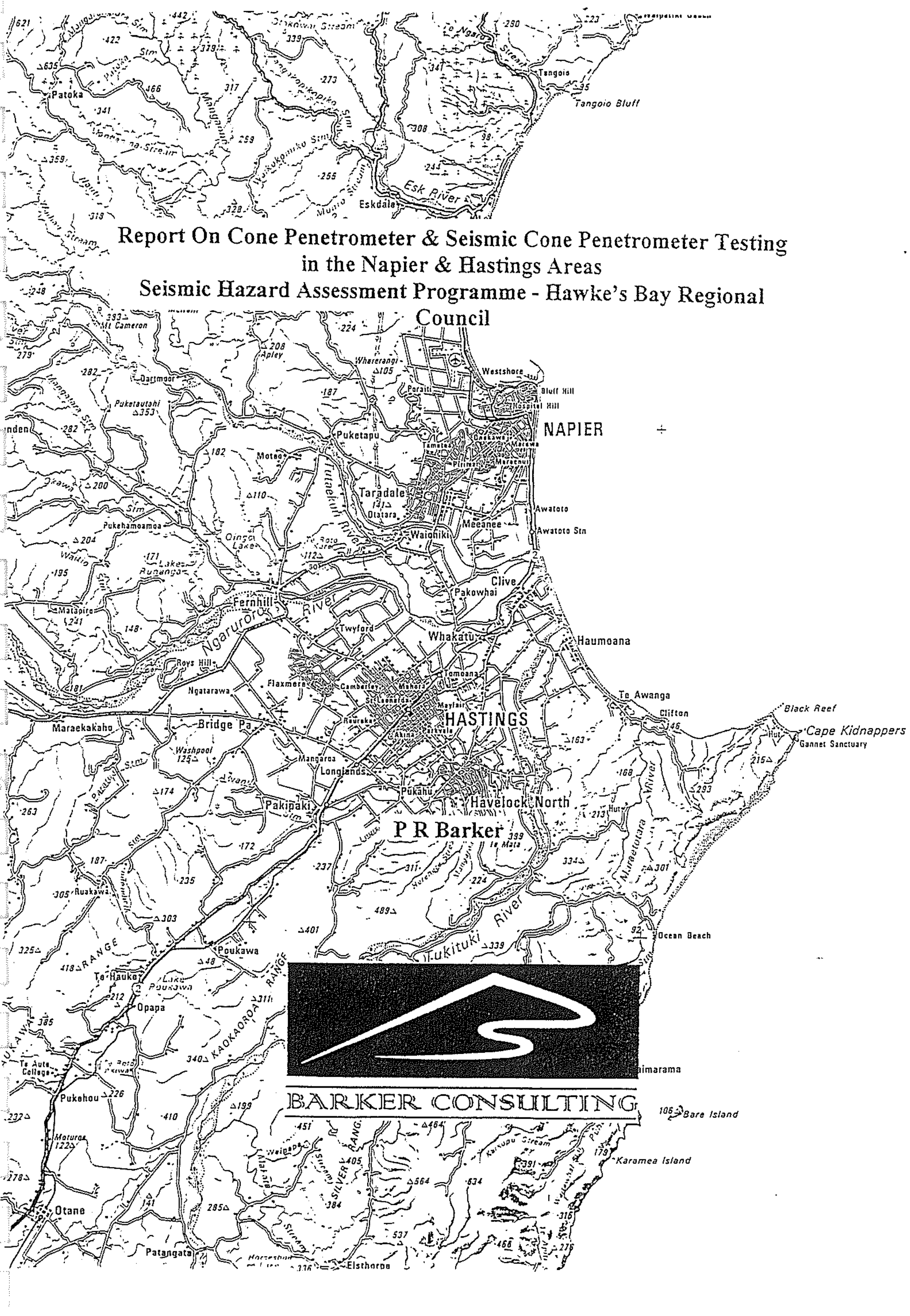


Fig. 32 CPT results - Waipawa

Report On Cone Penetrometer & Seismic Cone Penetrometer Testing in the Napier & Hastings Areas
Seismic Hazard Assessment Programme - Hawke's Bay Regional Council

P R Barker



BARKER CONSULTING

A Report On Cone Penetrometer & Seismic Cone Penetrometer Testing In the Napier & Hastings Areas Seismic Hazard Assessment Programme - Hawke's Bay Regional Council

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July 1997

Contents

1. Introduction

As part of the Institute of Geological and Nuclear Sciences input into the seismic hazard assessment programme being undertaken for the Hawke's Regional Council a series of cone penetrometer and seismic cone penetrometer probes were done by Barker Consulting.
The sites tested were (where possible) close to those used for the Nakamura micro tremor survey undertaken by IGNS.
Previous work by Barker Consulting has been done in the Napier area (Barker, 1994). As part of this work CPT and Seismic CPT tests were done at Napier City Council Works Depot (depth ~ 27m) and Kennedy Park (depth ~10m).

2. Outline of Work

Testing was undertaken at the following locations:

Nakamura Site No.	**Location**	**Test**
18	Napier Airport (Windsock Road)	CPT & SCPT
19	Westshore Domain - Napier	CPT & SCPT
new	Pirimai Domain -Napier	CPT & SCPT
21	Perfume Point - Napier	CPT
16	Clive	CPT & SCPT
12	Ormond Road - Hastings	CPT & SCPT
8	Hospital - Hastings	CPT & SCPT
6	Civil Defence - Hastings	CPT & SCPT

3. Equipment and Methods

3.1 Cone Penetration Test

The equipment and methods have been fully described in Stephenson and Barker (1989).

3.2 Seismic Cone Penetration Test

The equipment and methods have been fully described in Barker and Stephenson (1991) therefore only a brief outline is given here.
The seismic cone is attached to a standard CPT thrust rod and is pushed down the hole made by the CPT cone. A hammer blow at the surface generates a downward propagating horizontally polarised shear wave which is detected by a miniature geophone in the cone. The arriving seismic signal is logged on a laptop personal

computer for later processing. The process of generating and recording is repeated at 0.2m intervals.

4. Results

4.1 Napier Airport (Windsock Road)

4.1.1 Cone Penetration Test

This probe was located on the side of Windsock Road, on the western side of the main runway of Napier Airport, about 200 m north of the junction of Watchman and Windsock Roads; Fig. 1. This site was about 600 m west of Nakamura site 18. Probing commenced at 0.6m but was halted at 4.6m by a layer of gravel. In order to penetrate a layer this layer it was necessary to drill from 4.6 to 9.4m before recommencing probing. The drill cuttings showed that the gravel was clean, well rounded, stones up to 25 mm. and very little fines. From about 7m the cuttings were fine silty sands with some stones. Penetration was ceased at 22.3m when the friction sleeve became locked-up with fine silt.
Plots of point resistance and friction ratio versus depth are shown in Fig. 2.

A brief interpretation of the profile is:

0.6 - 2.0 m	medium dense sand
2.1 - 2.2 m	loose gravel
2.3 - 2.5 m	hard silty clay/ hard peat
2.6 - 3.1 m	dense silty sand/ gravelly sand
3.2 - 3.9 m	very soft clayey silt/ stiff peat
4.0 - 4.6 m	medium dense sand
# this section drilled - no record #	
9.4 - 9.5 m	medium dense clayey silty sand
9.6 - 20.6m	loose clayey silty sand/ silty sand
20.7 - 22.3m	medium dense clayey sandy silt/ stiff clayey silt

There is an indication that some material is potentially liquefiable material. This material is mainly about 10 cm thick and randomly scattered throughout the profile, however, there is a thicker layer from 0.8 - 1.3 m. The only record of material type in the drilled section was from the cuttings on the auger flights. Because the cuttings are a mixture of materials it not possible to determine textures and therefore it is not possible to indicate if potentially liquefiable material might be present within the drilled section.
The inferred material textures and potential liquefaction are shown in Fig. 3.

4.1.2 Seismic Cone Penetration Test

The seismic cone pushed to 24.2m. The hole was then backfilled with the cuttings so good physical contact with the probe and ground was made and shear-wave velocities in the upper 10 m could be obtained. A plot of the shear-wave arrival times against depth is shown in Fig. 4.

Four distinct zones can be identified:

0 - 4.0 m	with shear wave velocity of	124 m/sec
4.0 - 8.0 m	with shear wave velocity of	268 m/sec
8.0 - 16.0 m	with shear wave velocity of	166 m/sec
16.0 - 24 m	with shear wave velocity of	198 m/sec

There is an indication of a reflection from a deeper seismic layer, at about 38m, with a shear -wave velocity of about 200 m/sec. Where reflections are present they are a good sign of a change in material stiffness and therefore an indicator of resonance at the site. The expected frequency, on the basis of time to reflection, is about 1.2 Hz. Fig. 5. shows a plot of this interpretation.

4.2 Westshore Domain, Napier

4.2.1 Cone Penetration Test

This probe was located in the a grassed area on the Pump Road side of the domain and about 50m from the southern boundary with the river, Fig. 1. The site was about 300m west of the Nakamura site 19 on Embankment Road.
Probing commenced at 0.5m but was stopped at 4.7 m by a layer of gravel. In order to penetrate this layer it was necessary to drill from 4.7 to 9.6m. The drill cuttings showed that the gravel was clean, well rounded, stones up to 25 mm. with some fines. The cone reached refusal due to high point resistance at 15.5m. It is likely that the upper gravel layer at this site is the same as that encountered at the airport, although thicker and with more fine-grained material.
Plots of point resistance and friction ratio against depth are shown in Fig. 6.

A brief interpretation of the profile is:

0.5 - 1.3 m	medium dense clayey silty sand/ gravelly sand
1.3 - 3.0 m	loose sandy gravel with thin layers of medium dense gravelly sand
3.0 - 4.7 m	medium dense gravelly sand
	# this section drilled - no record #
9.6 - 10.3 m	medium dense sand/ silty sand
10.3 - 12.4 m	loose clayey sandy silt
12.4 - 12.8 m	firm clayey silt
12.8 - 14.5 m	loose sand/ gravelly sand with thin layers of dense silty sand
14.5 - 15.2 m	very stiff silty clay/ medium dense gravelly sand
15.2 - 15.5 m	dense gravelly sand

There is potentially liquefiable materials present at this site, however, it is generally in thin (10 - 20 cm) layer scattered throughout the profile. The only record of material types in the drilled section was from the cuttings on the auger flights. Because the cuttings are a mixture of materials it not possible to determine textures and therefore it is not possible to indicate if potentially liquefiable material might be present within the drilled section.

The inferred material textures and potential liquefaction are shown in Fig. 7.

4.2.2 Seismic Cone Penetration Test

The seismic cone was able to be pushed to 13.9m. The hole was then backfilled with the cuttings so good physical contact with the probe and ground was made and shear-wave velocities in the upper 10 m could be obtained. A plot of the shear-wave arrival times against depth is shown in Fig. 8. There is evidence of a converted P wave (?) arrival at depths below 6m.
Three distinct zones can be identified:

0 - 2.8 m	with shear wave velocity of	108m/sec
2.8 - 9.5 m	with shear wave velocity of	235m/sec
9.5 - 15.6m	with shear wave velocity of	169m/sec

There is no indication of any reflection from a deeper seismic layer.

Fig. 9. shows a plot of this interpretation.

4.3 Pirimai Domain, Napier

4.3.1 Cone Penetration Test

This probe was located on the edge of the playing area next to the paved parking area adjacent to the Pirimai shops, Fig. 10.
Probing commenced at 0.5m. The probe reached 16.8m before it was stopped by high side friction. Plots of point resistance and friction ratio against depth are shown in Fig. 11.

A brief interpretation of the profile is:

0.5 - 1.7 m	loose silty sand
1.7 - 4.3 m	very loose silty sand/ very soft silty clay
4.3 - 4.4 m	stiff peat
4.4 - 5.1 m	medium dense sand
5.1 - 6.0 m	very loose sandy gravel/ gravel
6.0 - 6.7 m	medium dense clayey silty sand
6.7 - 8.0 m	loose clayey silty sand
8.0 - 9.0 m	medium dense clayey silty sand
9.0 - 9.6 m	loose sand/ gravel
9.6 - 12.0 m	medium dense silty sand with thin layers of loose gravelly sand
12.0 - 16.8 m	dense clayey silty sand/ clayey sandy silt

The interpretation indicates that most of the material between 8 - 13 m is potentially liquefiable. There are also a few thin (10 cm) layers at shallower depths.
The inferred material textures and potential liquefaction are shown in Fig. 12.

4.3.2 Seismic Cone Penetration Test

The seismic cone pushed to 17.3m. A plot of the shear-wave arrival times against depth is shown in Fig. 13.

Three zones can be identified:

0 - 3.5 m	with shear wave velocity of 78 m/sec
3.5 - 10.5 m	with shear wave velocity of 142 m/sec
10.5 - 17.4 m	with shear wave velocity of 200 m/sec

There is no indication of a reflection from a deeper seismic layer.

Fig. 14. shows a plot of this interpretation.

4.4 Perfume Point

4.4.1 Cone Penetration Test

The site was located in the center of the new reserve area (originally the Mobil Oil N Z petrol storage tank farm) at the entrance to the Westshore Inner Harbour, Fig. 10. This site was about 150 m west of site 21 in the Nakamura survey.
Probing commenced at 0.5m. The probe reached 1.9m before it was stopped by a layer with high penetration resistance. Plots of point resistance and friction ratio against depth are shown in Fig. 15.

A brief interpretation of the profile is:

0.5 - 1.6 m	medium dense gravelly sand
1.6 - 1.9 m	dense gravelly sand

There is no potentially liquefiable material at this site; as shown on the inferred material texture plot, Fig. 16.

4.5 Clive

4.5.1 Cone Penetration Test

The site was located on the western bank of the Clive River midway between the Clive Rowing Club and the road bridge over the Clive, Fig. 17. The site was about 150 m south of site 16 in the Nakamura survey.
Probing commenced at 0.5m. The probe reached 6.7m before it was stopped by a high penetration resistance layer. Plots of point resistance and friction ratio against depth are shown in Fig. 18.

A brief interpretation of the profile is:

0.5 - 1.1 m	medium dense clayey silty sand
1.1 - 4.1 m	very loose silty sand/ very soft clayey silt
4.1 - 6.1 m	medium dense gravelly sand/ dense silty sand
6.2 - 6.6 m	medium dense gravel

There is a very small amount of potentially liquefiable material at this site. This is in occasionally thin layers between 0.9 and 4.5 m. The inferred material texture and potential liquefaction plot is shown in Fig. 19.

4.5.2 Seismic Cone Penetration Test

The seismic cone pushed to 6.8m. A plot of the shear-wave arrival times against depth is shown in Fig. 20.
Two distinct zones can be identified:

0 - 4.0 m	with shear wave velocity of 73 m/sec
4.0 - 6.8 m	with shear wave velocity of 164 m/sec

There is no evidence of a reflection from a deeper seismic layer.

Fig. 21. shows a plot of this interpretation.

4.6 Ormond Road, Hastings

4.6.1 Cone Penetration Test

The site was located at the end of Ormond Road, on the grass verge just inside the entrance gate of the road leading to the Clive River, Fig. 17. The site was about 50 m from site 12 in the Nakamura survey.
Probing commenced at 0.5m. The probe reached 17.7m before it was stopped by a high penetration resistance layer. Plots of point resistance and friction ratio against depth are shown in Fig. 22.

A brief interpretation of the profile is:

0.5 - 0.9 m	medium dense silty sand
0.9 - 2.8 m	loose silty sand
2.8 - 3.8 m	firm silty clay/medium dense silty sand
3.8 - 5.1 m	medium dense silty sand/ firm silty clay
5.1 - 6.3 m	loose clayey silty sand
6.3 - 7.0 m	medium dense clayey sandy silt
7.0 - 7.4 m	loose clayey sandy silt
7.4 - 9.1 m	dense clayey silty sand
9.1 - 9.6 m	stiff- very stiff clay
9.6 - 10.5 m	medium dense/ dense clayey sandy silt
10.5 - 14.0 m	loose silty sand
14.0 - 16.1 m	medium dense silty sand/ firm clayey silt
16.1 - 16.6 m	loose clayey silty sand
16.6 - 17.5 m	medium dense clayey sandy silt/ very stiff clayey silt
17.5 - 17.7 m	dense gravelly sand

There is potentially liquefiable material at this site. It is mainly in thin layers scattered throughout the profile, however, there are four depths where it is considerably thicker; 1.5 - 2.9 m, 11.1 - 11.8 m, 12.3 - 12.6 m, and 13.7 - 14.0 m. The inferred material texture and potential liquefaction plot is shown in Fig. 23.

4.6.2 Seismic Cone Penetration Test

The seismic cone was able to be pushed to 17.7 m. A plot of the shear-wave arrival times against depth is shown in Fig. 24.

Three zones can be identified:

0 - 6.5 m	with shear wave velocity of 104 m/sec
6.5 - 14 m	with shear wave velocity of 154 m/sec
14 - 18 m	with shear wave velocity of 260 m/sec

There is evidence of a reflection from a deeper seismic layer, at about 21m, with a shear-wave velocity of about 250 m/sec. Where reflections are present they are a good sign of a change in material stiffness and therefore an indicator of resonance at the site. The expected frequency, on the basis of time to reflection, is about 1.7 Hz.

Fig. 25. shows a plot of this interpretation.

4.7 Hospital, Hastings

4.7.1 Cone Penetration Test

The site was located in the vacant section (on the north eastern side of Omahu Road, opposite the Hastings Hospital) next to the construction of new halfway houses for the Hastings CHE, Fig. 26. It was about 50 m from site 8 in the Nakamura survey. Probing commenced at 0.5m. The probe reached 10.7m before it was stopped by high side friction. Plots of point resistance and friction ratio against depth are shown in Fig. 27.

A brief interpretation of the profile is:

0.5 - 2.3 m	medium dense silty sand with thin layers of loose sandy gravel
2.3 - 6.2 m	layers of loose silty sand/ soft clayey silt/ firm silty clay
6.2 - 7.4 m	medium dense silty sand
7.4 - 8.0 m	stiff clayey silt
8.0 - 9.1 m	medium dense clayey silty sand
9.1 - 10.7 m	dense clayey silty sand/ clayey sandy silt

There is a small amount of potentially liquefiable material at this site. It is mainly in thin (10- 20 cm) layers throughout the top 3 m. There are also a few layers between 5 and 8 m. The inferred material texture and potential liquefaction plot is shown in Fig. 28.

4.7.2 Seismic Cone Penetration Test

The seismic cone pushed to 10.8 m. A plot of the shear-wave arrival times against depth is shown in Fig. 29.
Two zones can be identified:

0 - 5.6 m	with shear wave velocity of 117 m/sec
5.6 - 10.8 m	with shear wave velocity of 162 m/sec

There is an indication of a reflection from a deeper seismic layer, at about 17 m, with a shear-wave velocity of about 214 m/sec. Where reflections are present they are a good sign of a change in material stiffness and therefore an indicator of resonance at the site. The expected frequency, on the basis of time to reflection, is about 1.6 Hz.

Fig. 30. shows a plot of this interpretation.

4.8 Civil Defence, Hastings

4.8.1 Cone Penetration Test

The site was located on the grass between the Civil Defence building and the CD garage, about 5m from the paved area, Fig. 26. It was about 10 m from site 6 in the Nakamura survey.
Probing commenced at 0.5m but was halted by a layer of gravel at 1.8 m and again at 3.5 m. In order to penetrate these layers it was necessary to drill from 1.8 - 3.0 m and 3.5 to 9.4 m. The drill cuttings indicated that the material was a silty sandy gravel with rounded stones up to 35 mm. Penetration was ceased at 12.2m when the friction sleeve locked-up with fine silt.
Plots of point resistance and friction ratio versus depth are shown in Fig. 31.

A brief interpretation of the profile is:

0.5 - 1.4 m	made ground
1.4 - 1.7 m	medium dense gravel
	# this section drilled - no record #
3.0 - 3.5 m	dense gravelly sand
	# this section drilled - no record #
9.5 - 9.9 m	dense clayey sandy silt
9.9 - 10.8 m	medium dense clayey silty sand
10.8 - 11.3 m	dense clayey sandy silt
11.4 - 12.2 m	dense silty sand

There is a very small amount of potentially liquefiable material at this site. It is thin layers scattered throughout the profile. The only record of material type in the drilled section was from the cuttings on the auger flights. Because the cuttings are a mixture of materials it not possible to determine textures and therefore it is not possible to indicate if potentially liquefiable material might be present within the drilled section.

The inferred material texture and potential liquefaction plot is shown in Fig. 32.

4.8.2 Seismic Cone Penetration Test

The seismic cone was able to be pushed to 9.8m. The hole was then backfilled with the cuttings so good physical contact with the probe and ground was made and shear-wave velocities in the upper 10 m could be obtained. A plot of the shear-wave arrival times against depth is shown in Fig. 33.
Three zones can be identified:

0 - 5.6 m	with shear wave velocity of 226 m/sec
5.6 - 8.8 m	with shear wave velocity of 148 m/sec
8.8 - 11.6 m	with shear wave velocity of 218 m/sec

There is no indication of a reflection from a deeper seismic layer.

Fig. 34. shows a plot of this interpretation.

5. General Comments

5.1 Confidence Limits

The cone penetrometer was designed principally for use in fine-grained sediments and is not capable of operating through dense gravelly materials. The equipment used for this work has only a 3 tonne thrust capacity and sometimes when operating in fine-grained sediments an accumulation of side friction on the sounding rods can prevent further penetration. This does not mean that this technique is inappropriate but that higher capacity equipment might be able to advance further.
The point resistance values shown in the figures are accurate to +/- 400 kPa for readings over 2 MPa, and to +/- 70 kPa for readings under 2 MPa. The friction ratio values have an accuracy of +/- 20% of the plotted values when uniform materials are being penetrated, but when the materials change rapidly the accuracy is less because the point can be in one type of material and the friction sleeve in another. The Searle Diagram (Searle, 1979) is used only to provide an indication of the material types encountered.

The measured downward propagating seismic velocities are accurate to +/- 5m/sec. However, it is more difficult to determine reflected velocities (when reflections are able to be identified) because there is usually less reliable data available and therefore the interpretation becomes more subjective; the accuracy would be +/- 25m/sec.

The ability to identify a reflected wave below the depth of the cone depends on the how close that layer is to the cone. Where the reflecting layer is just below the cone the reflected waves are often difficult to identify because they are mixed with the downward propagating waves. Also if the impedance ratio between the two layers is low then this can greatly lower the ability to identify a reflection and may lead to greater inaccuracies in determining the reflected velocity. However, if the reflecting layer is deeper than the cone by 5m or more then the reflected signal is often easier to identify and not confused by the downward waves.

5.2 Liquefaction

Cyclic liquefaction occurs in geologically recent fine sands and silts below the water table. The presence of a significant quantity (> 20%) of clay sized particles renders the soil cohesive and therefore not susceptible to cyclic liquefaction. Also the presence of soil particles with a range of sizes leads to interstitial spaces being filled, higher densities and hence low susceptibility to liquefaction.
The assessment of potential liquefaction is based on the regime defined by Robertson and Campanella (1985) and that materials coarser than gravelly sand (Searle's 1979 criterion) will not liquefy. In the inferred texture diagrams the division between

inferred cohesive (non liquefiable) and inferred non cohesive soils is between clayey silt and clayey sandy silt. The liquefiable/non liquefiable boundary is shown as a dashed line on the inferred texture diagrams. Although this boundary applies strictly to results obtained with an electric cone it will be similar for results with the mechanical cone used in the work. Materials to the left of the curve are potentially liquefiable.

6. References

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7. Acknowledgments

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Bill Stephenson, IGNS, for his helpful comments and computer skills.

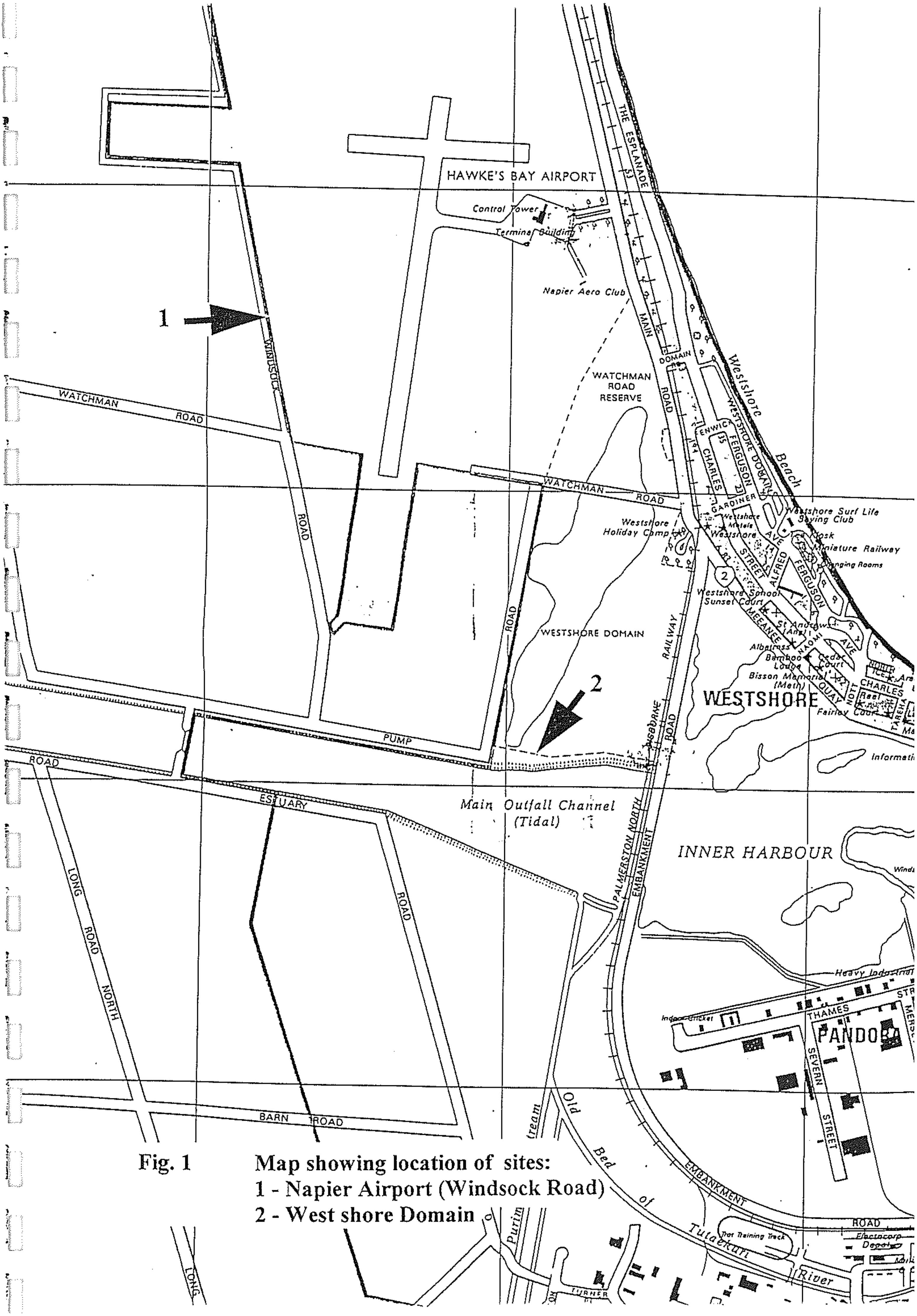

Fig. 1 Map showing location of sites:
1 - Napier Airport (Windsock Road)
2 - West shore Domain

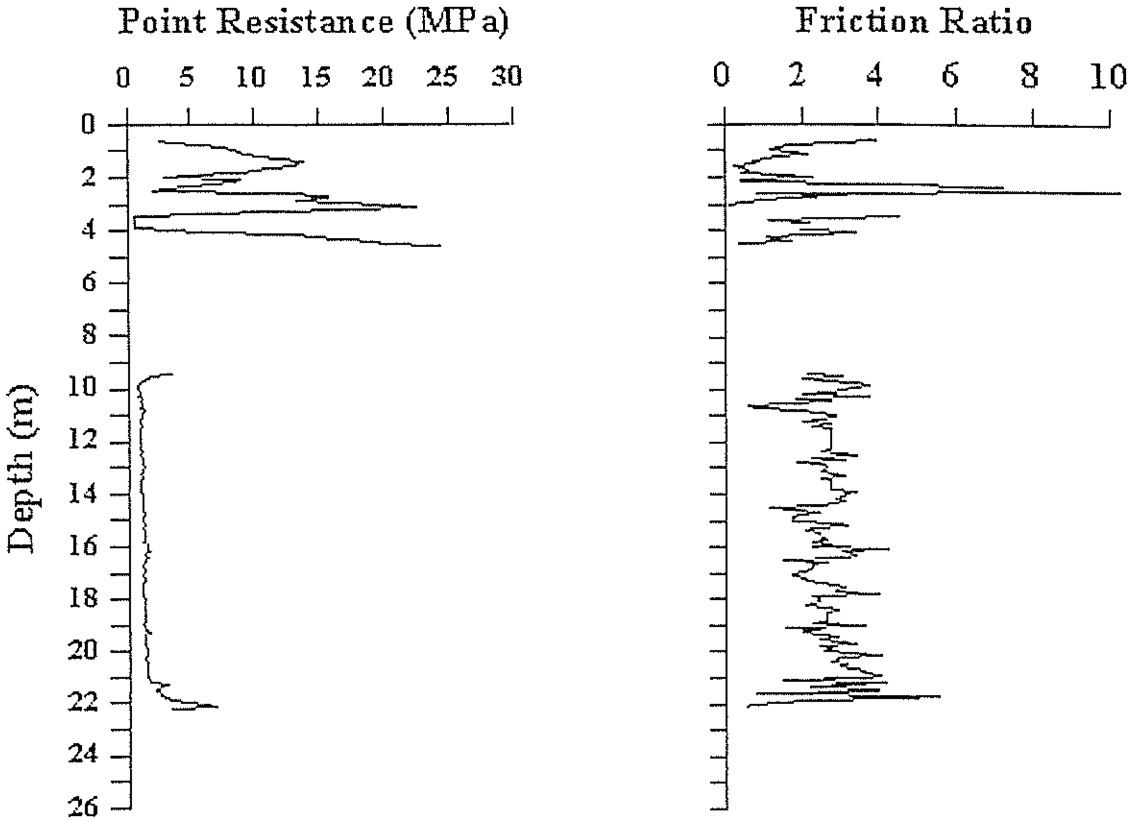

Fig. 2 CPT results - Napier Airport (Windsock Road)

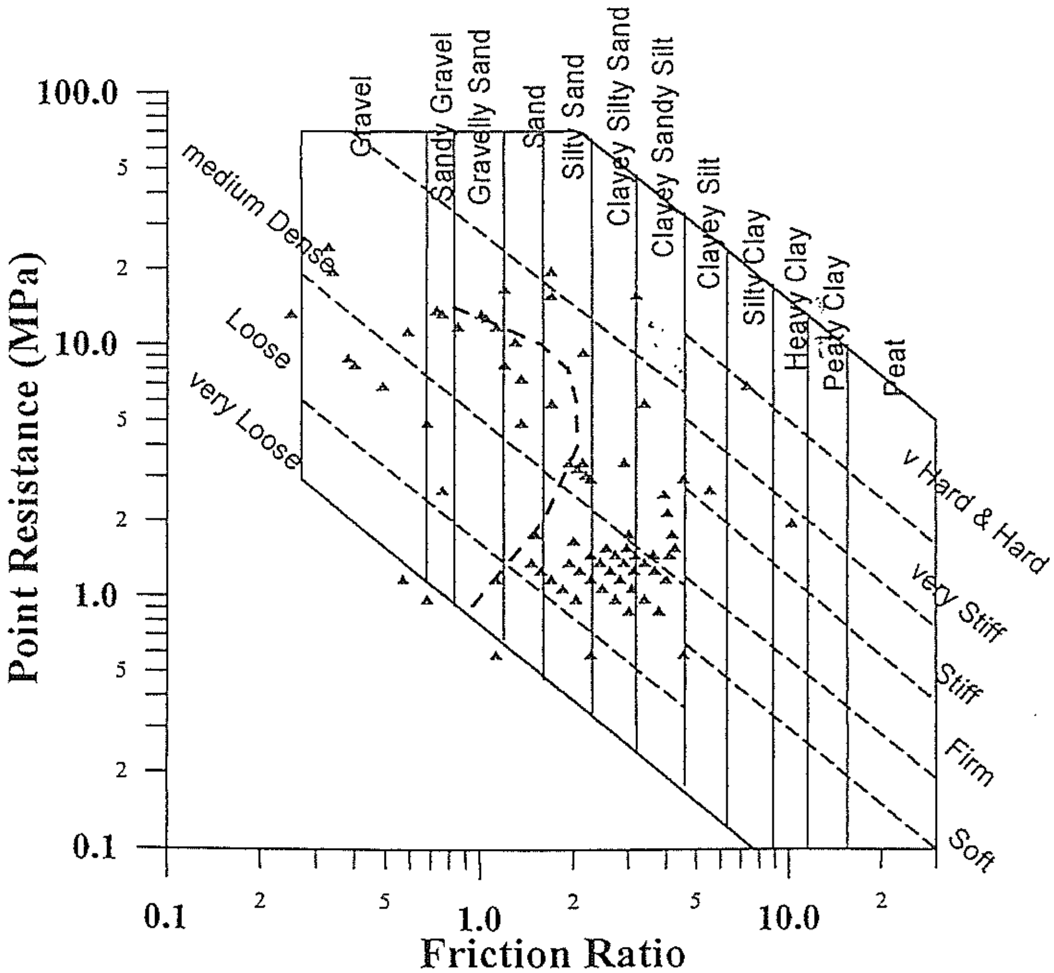

Fig. 3 Inferred texture & potential liquefaction - Napier Airport (Windsock Road)

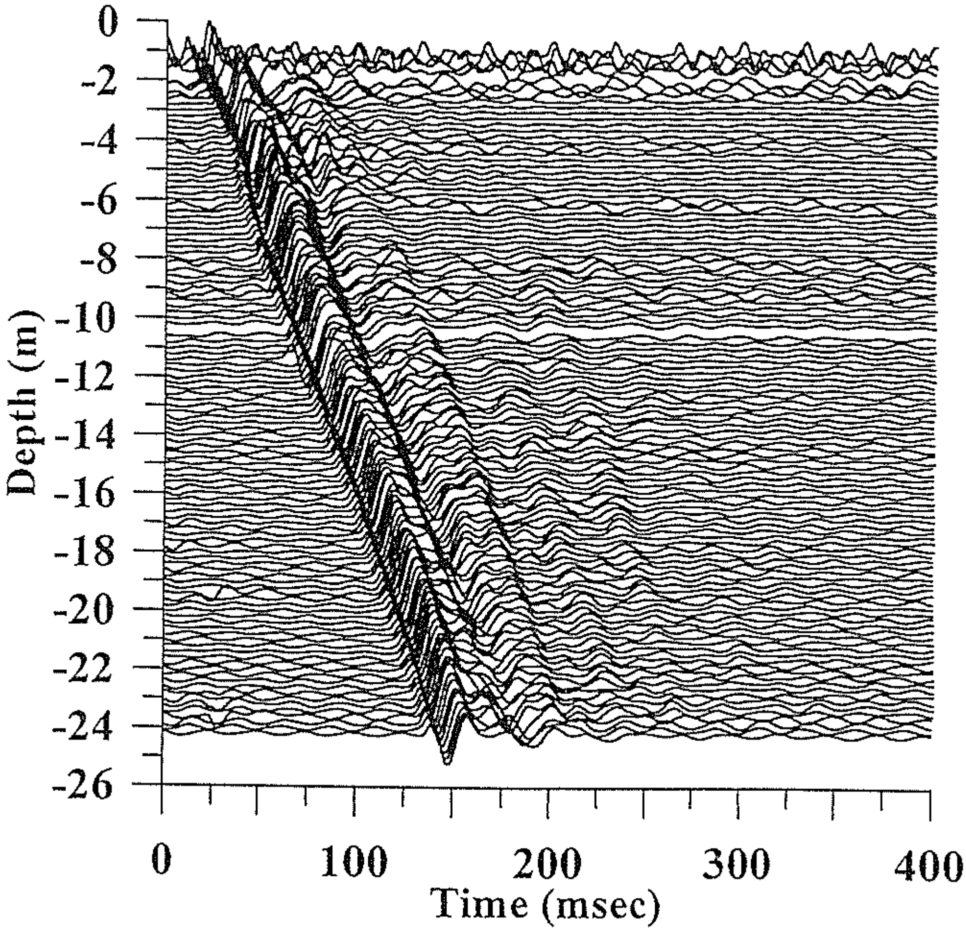

Fig. 4 Seismic CPT results - Napier Airport (Windsock Road)

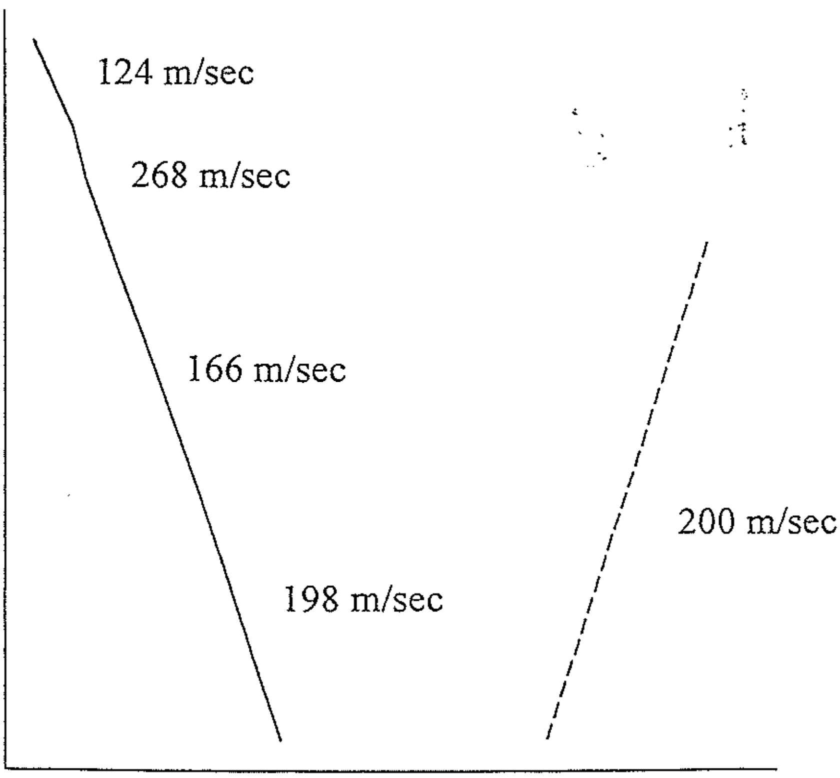

Fig. 5 Interpretation - Napier Airport (Windsock Road)

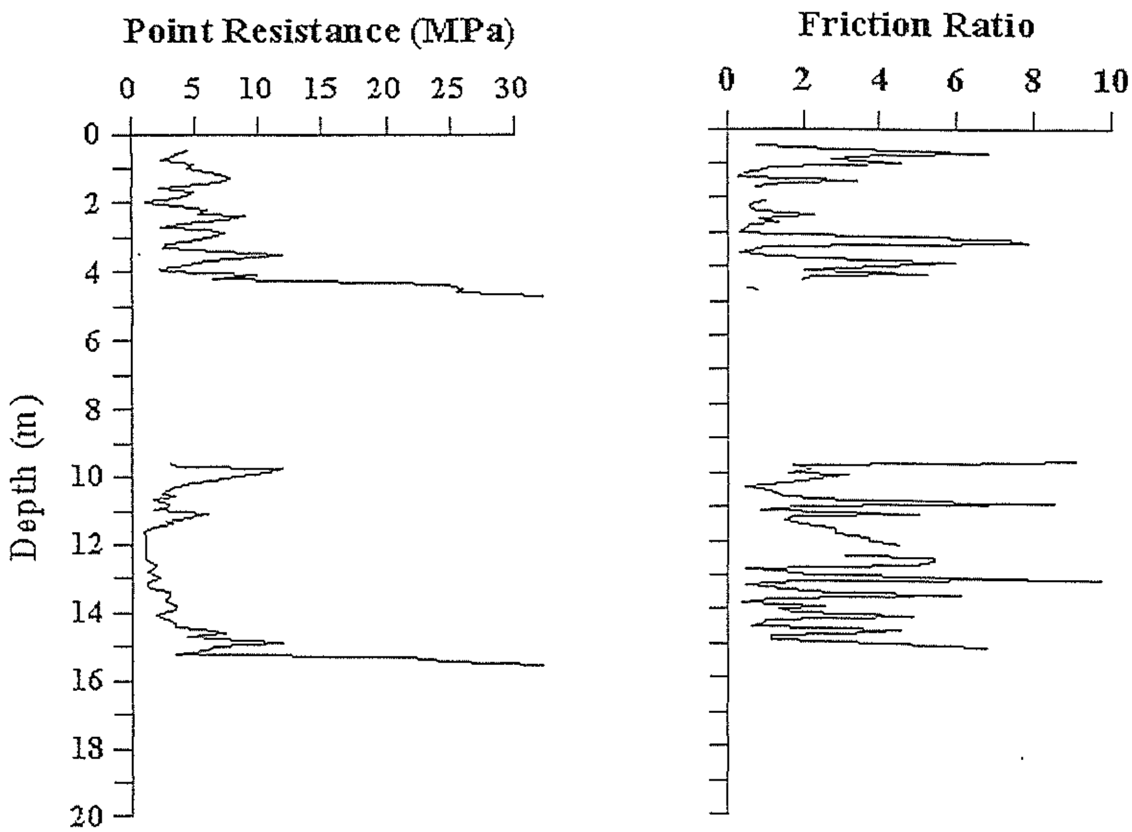

Fig. 6 CPT results - Westshore Domain, Napier

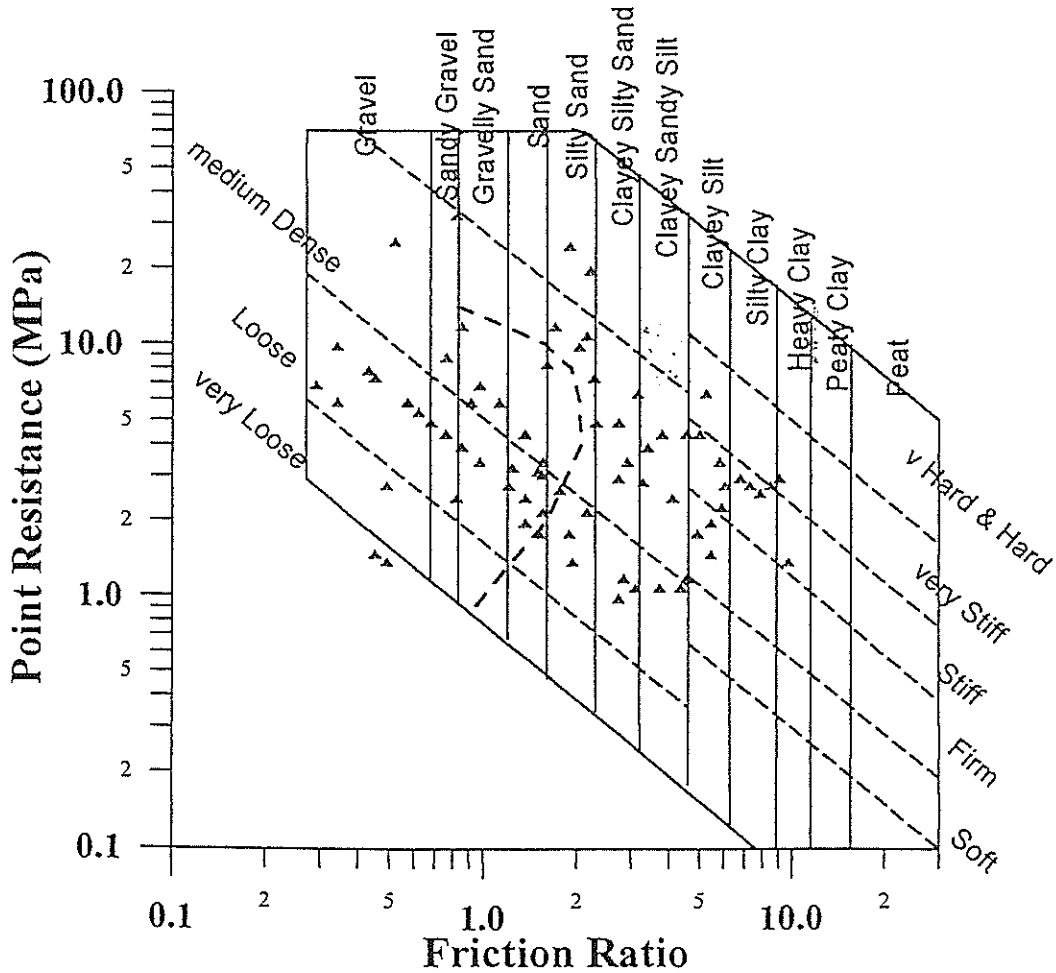

Fig. 7 Inferred texture & potential liquefaction - Westshore Domain, Napier

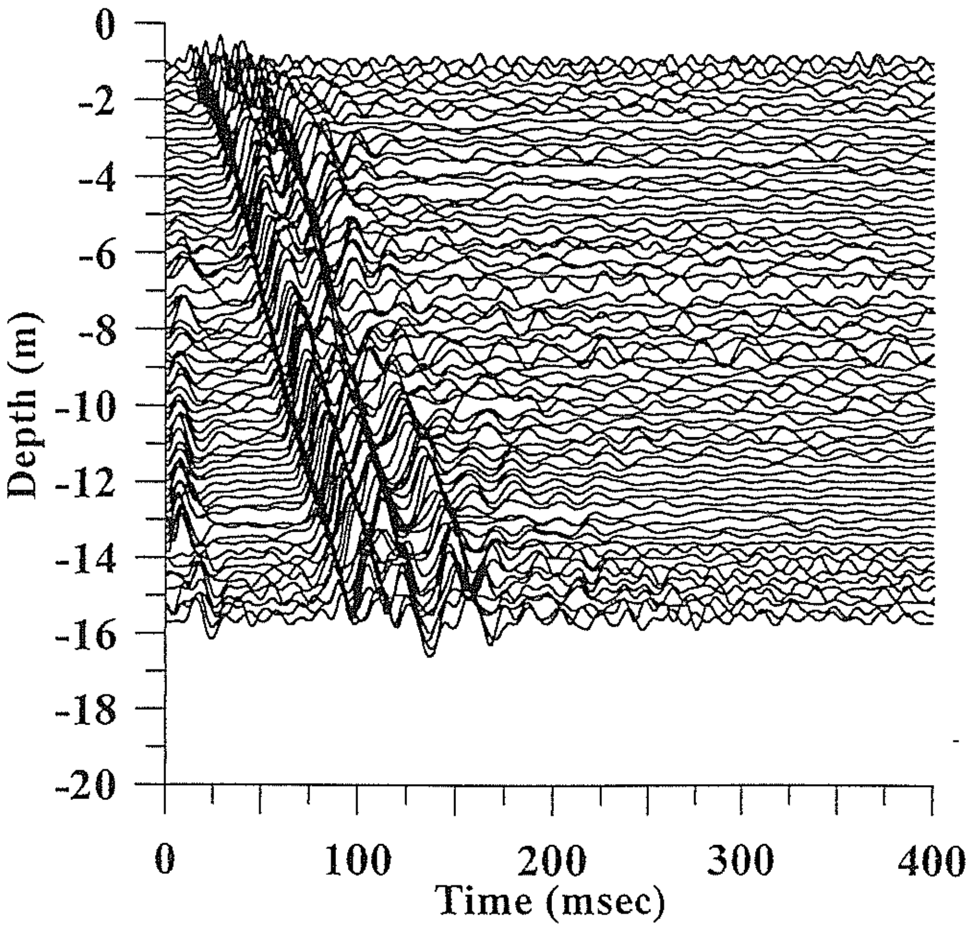

Fig. 8 Seismic CPT results - Westshore Domain, Napier

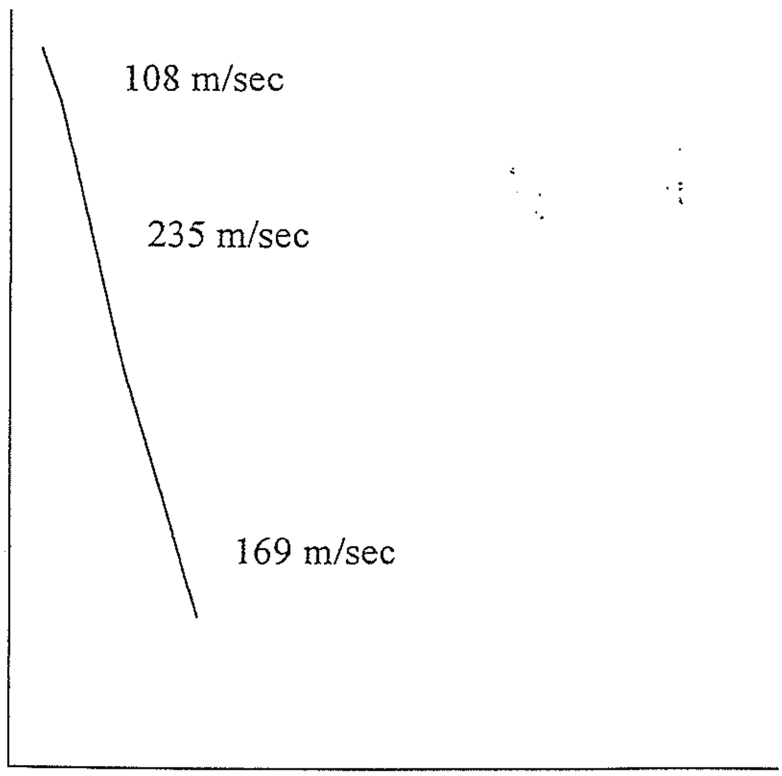

Fig. 9 Interpretation - Westshore Domain, Napier

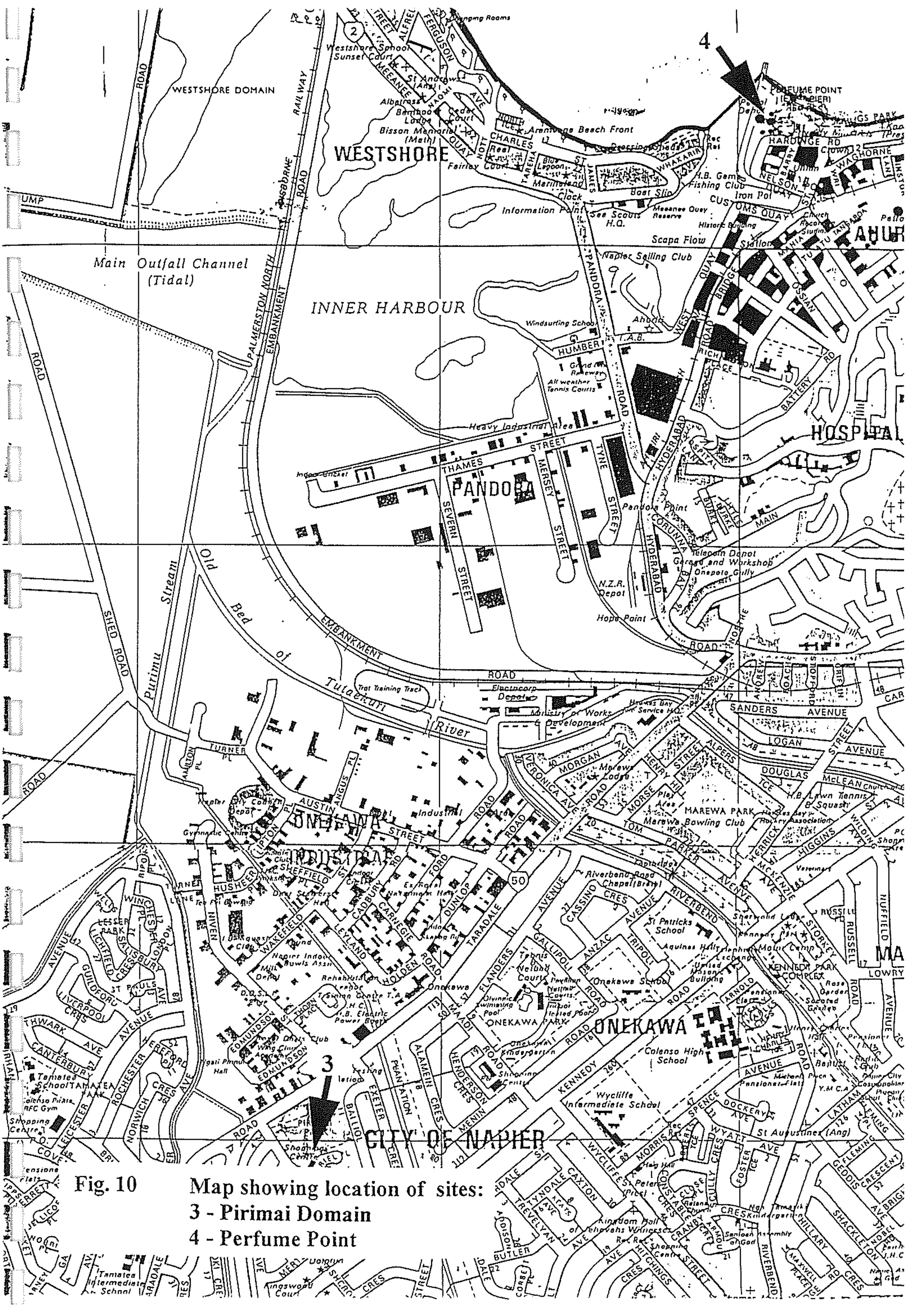

Fig. 10 Map showing location of sites:
3 - Pirimai Domain
4 - Perfume Point

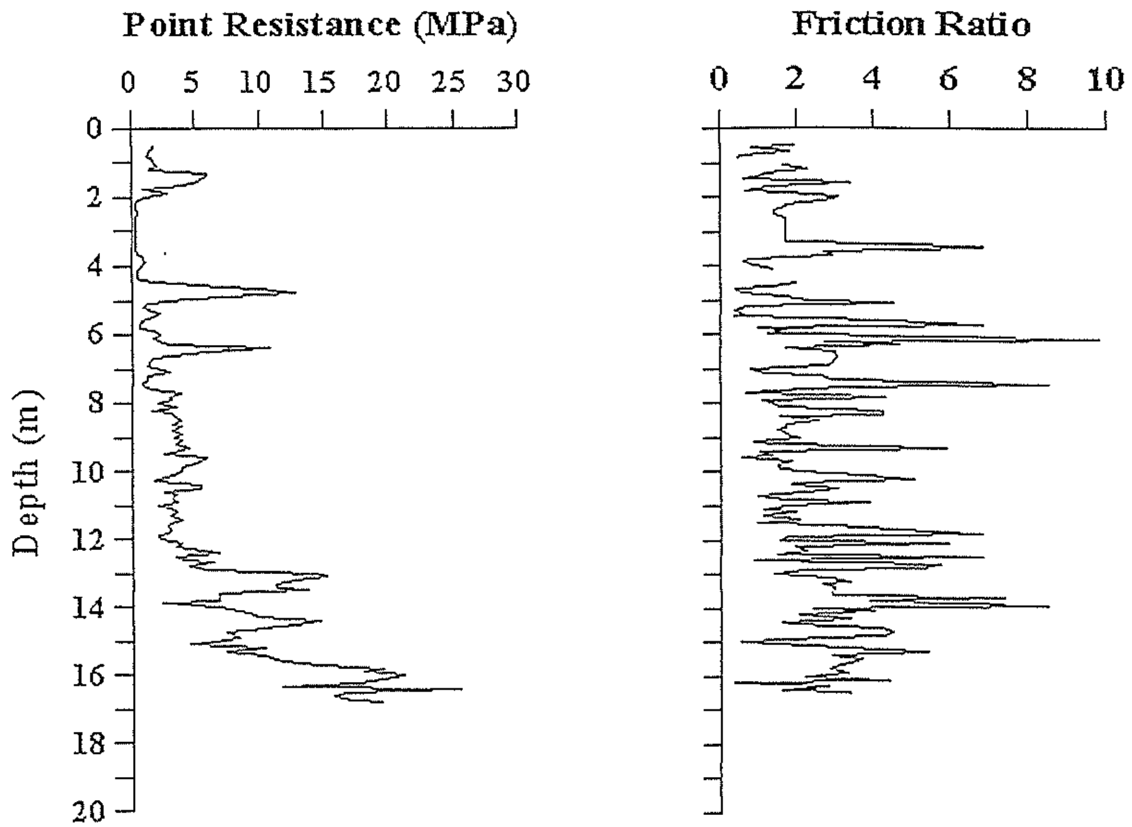

Fig. 11 CPT results - Pirimai Domain, Napier

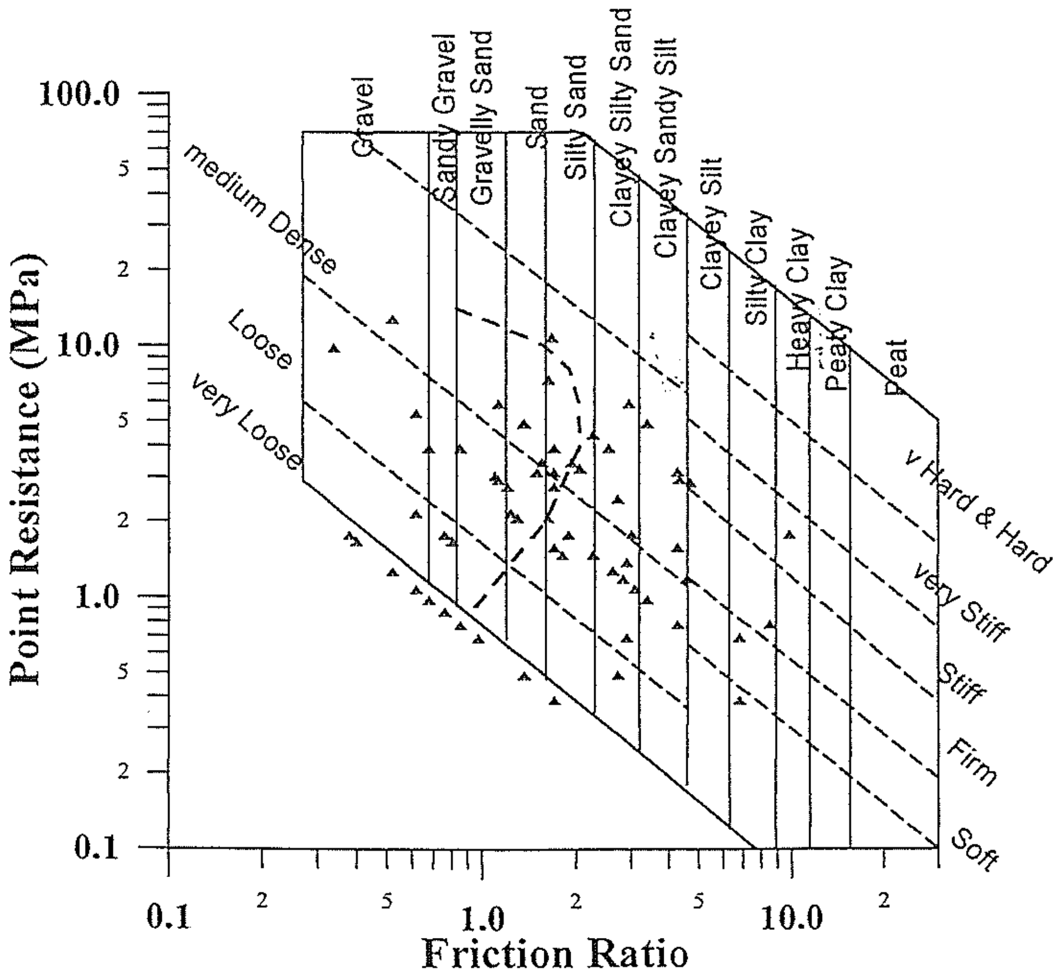

Fig. 12 Inferred texture & potential liquefaction - Pirimai Domain, Napier

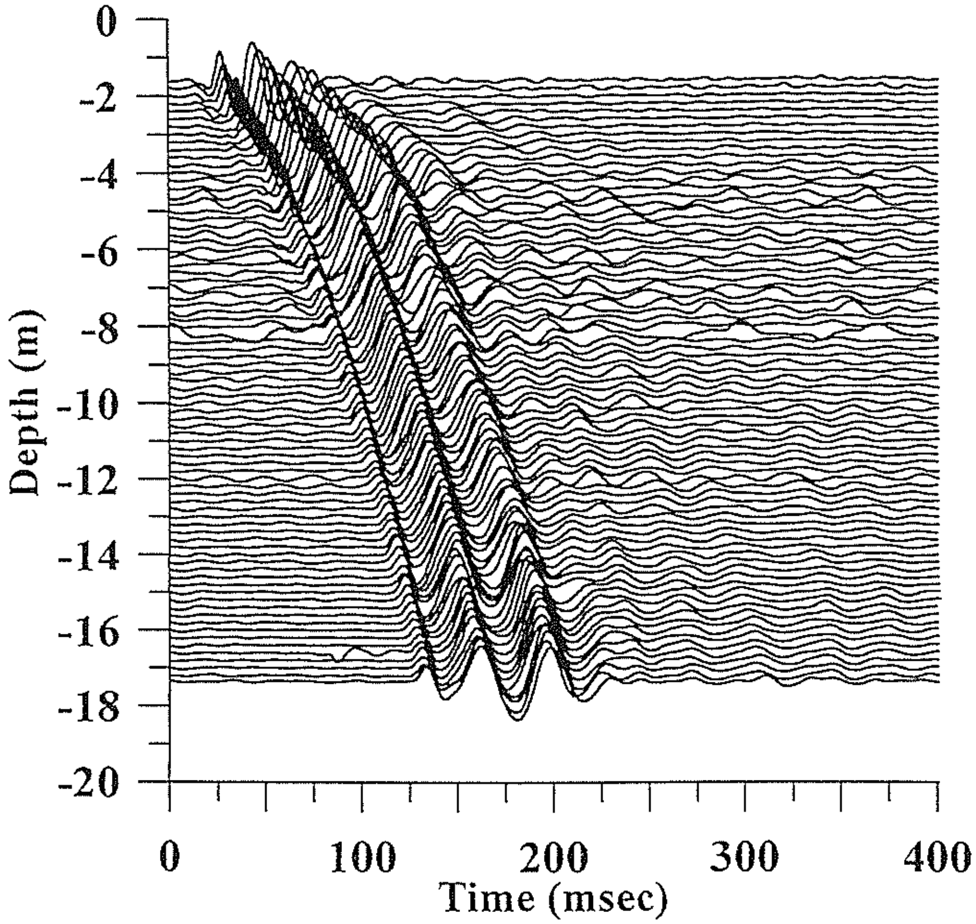

Fig. 8 Seismic CPT results - Pirimai Domain, Napier

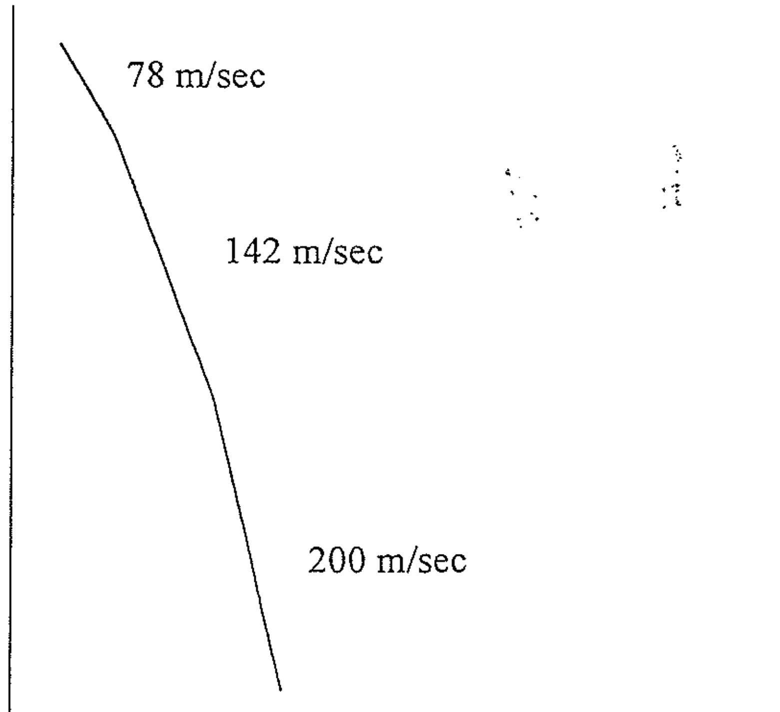

Fig. 13 Interpretation - Pirimai Domain, Napier

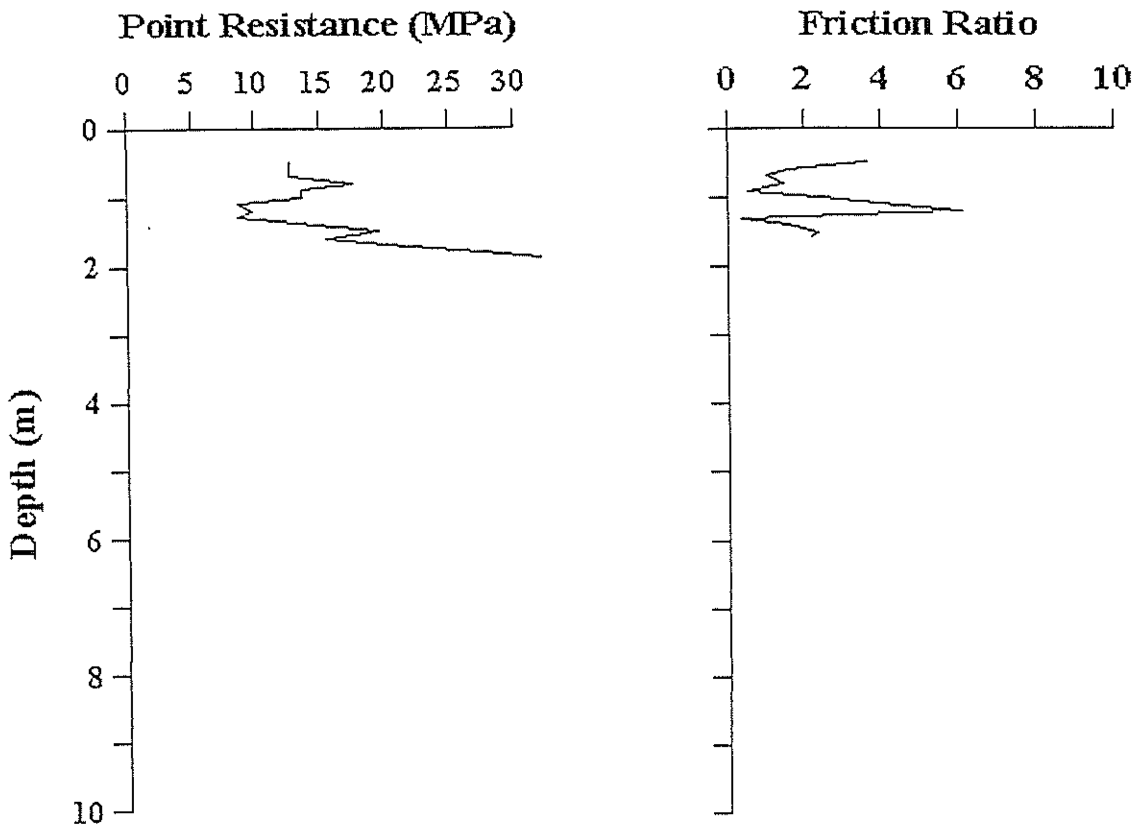

Fig. 15 CPT results - Perfume Point, Napier

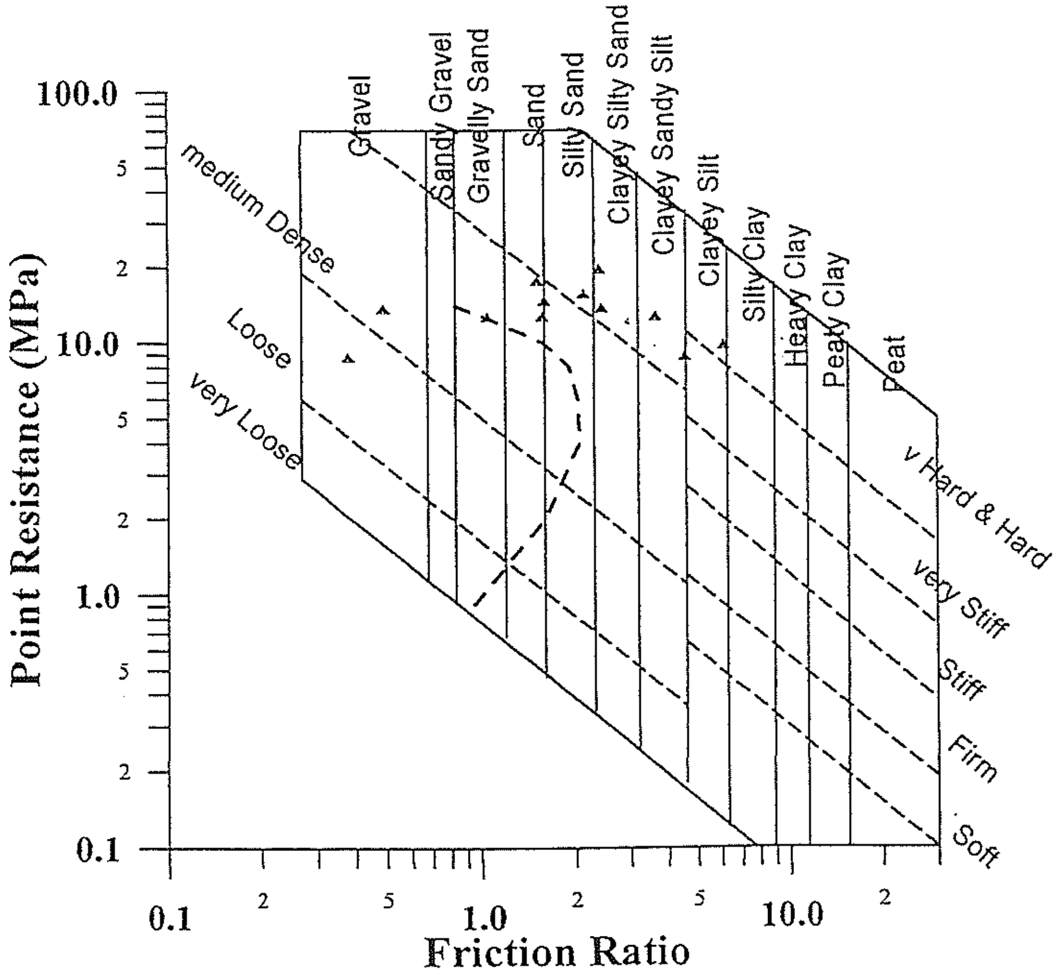

Fig. 16 Inferred texture & potential liquefaction - Perfume Point, Napier

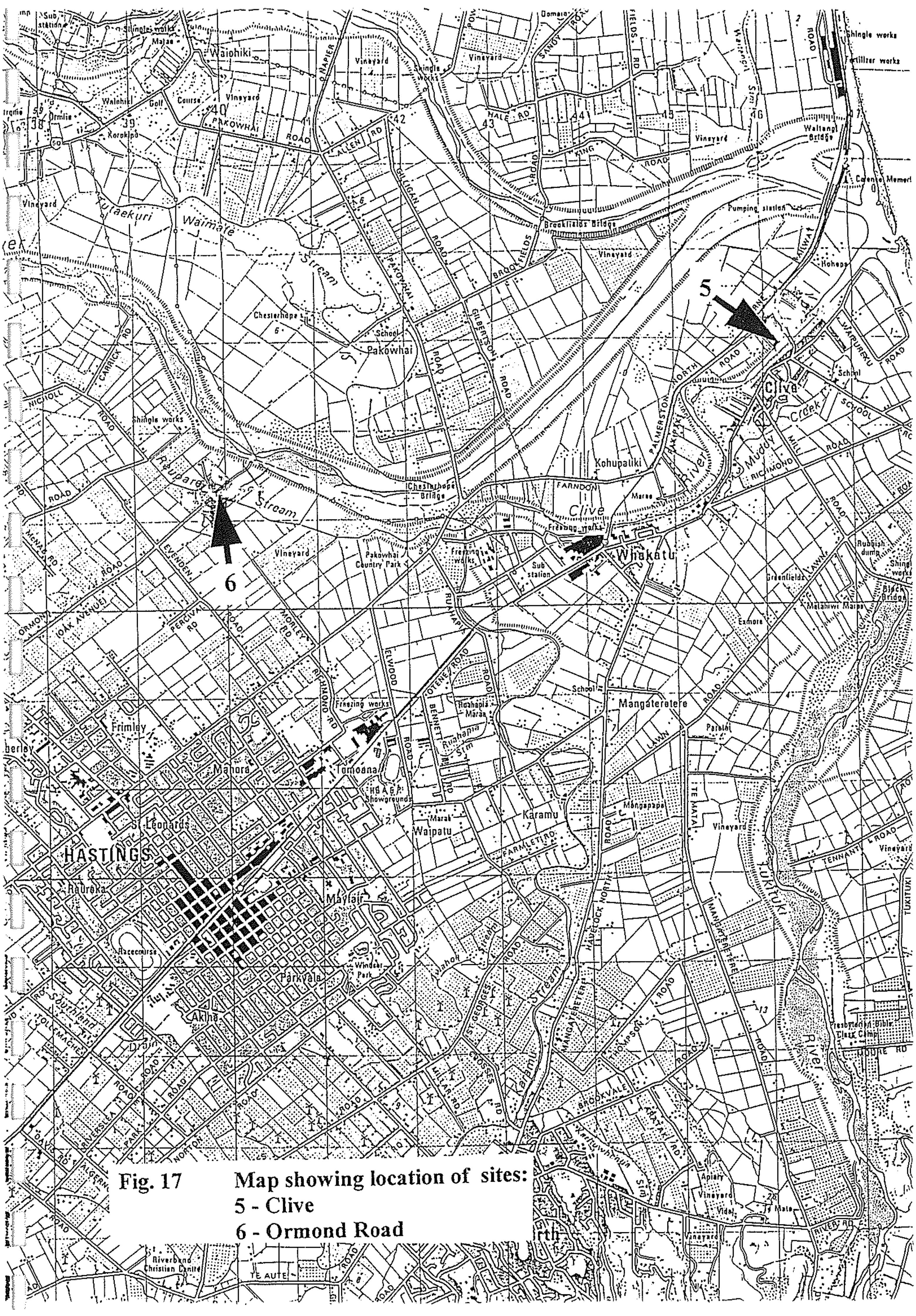

Fig. 17 Map showing location of sites:
5 - Clive
6 - Ormond Road

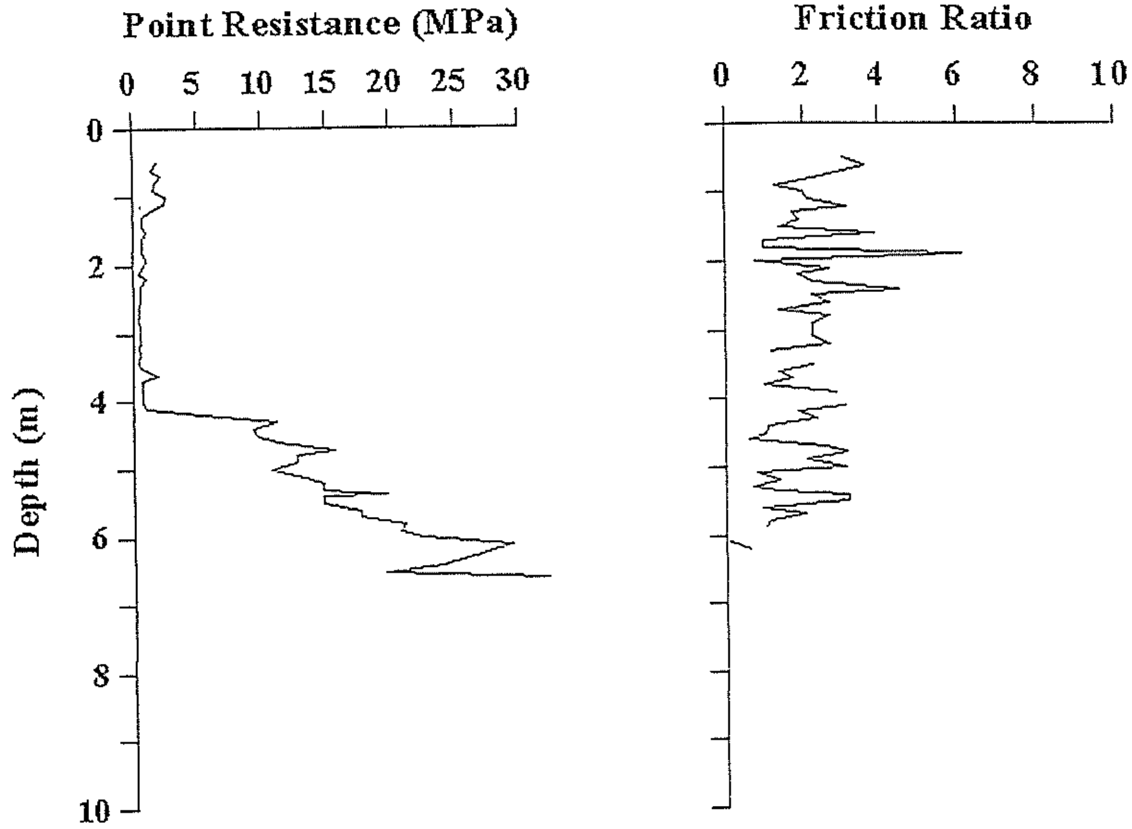

Fig. 18 CPT results - Clive

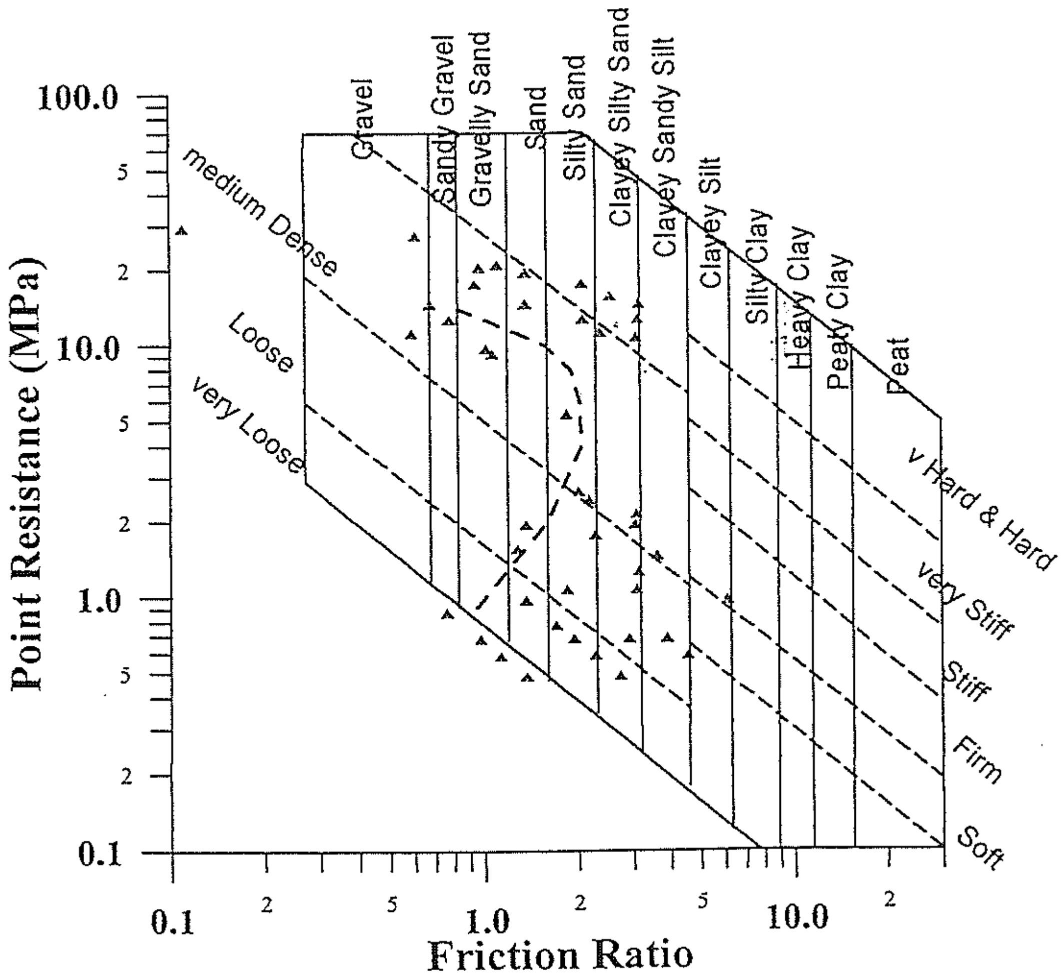

Fig. 19 Inferred texture & potential liquefaction - Clive

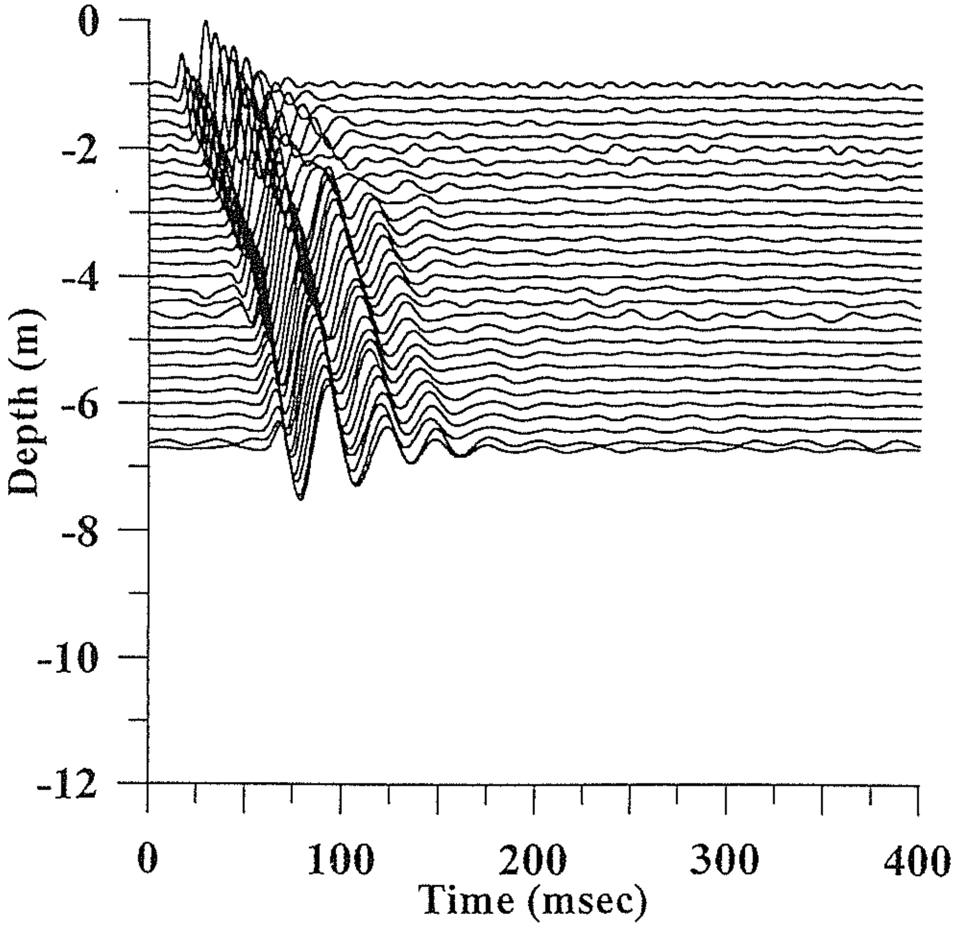

Fig. 20 Seismic CPT results - Clive

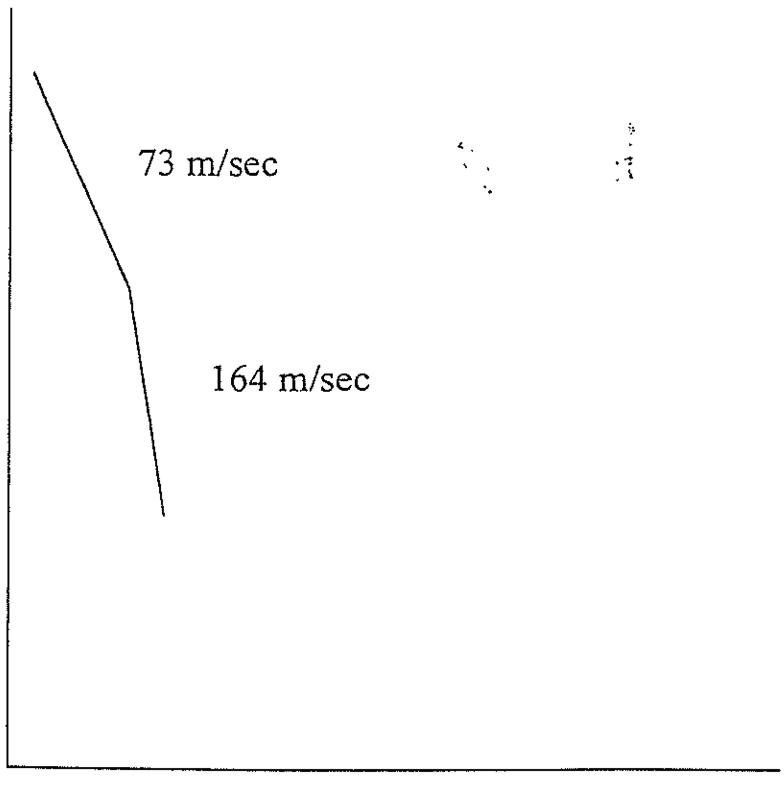

Fig. 21 Interpretation - Clive

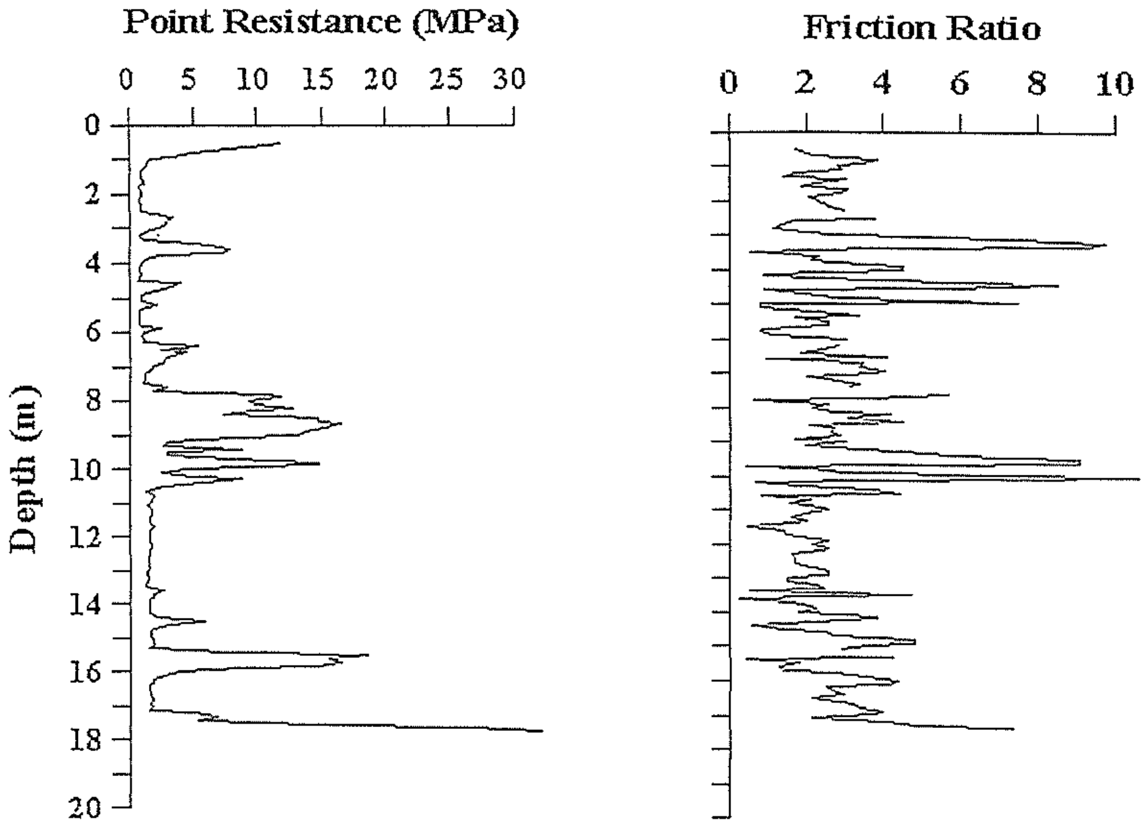

Fig. 22 CPT results - Ormond Road, Hastings

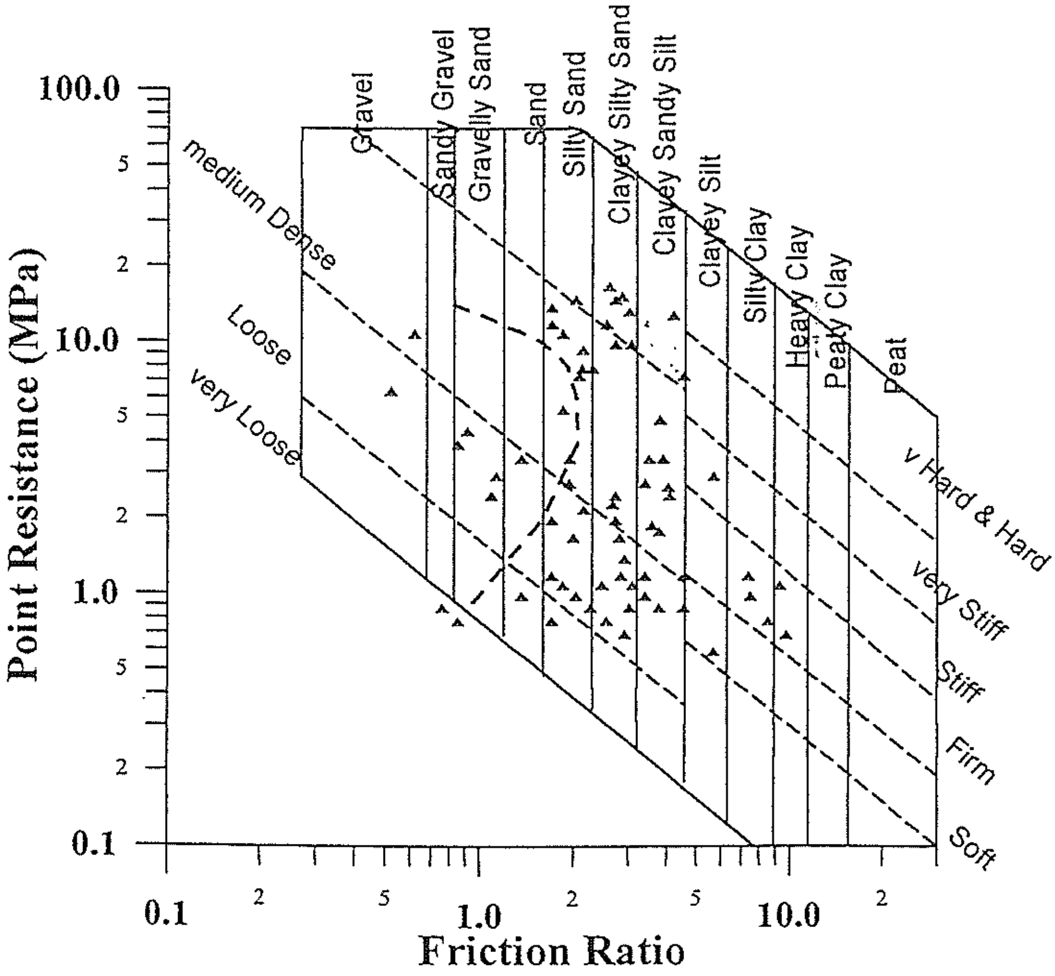

Fig. 23 Inferred texture & potential liquefaction - Ormond Road, Hastings

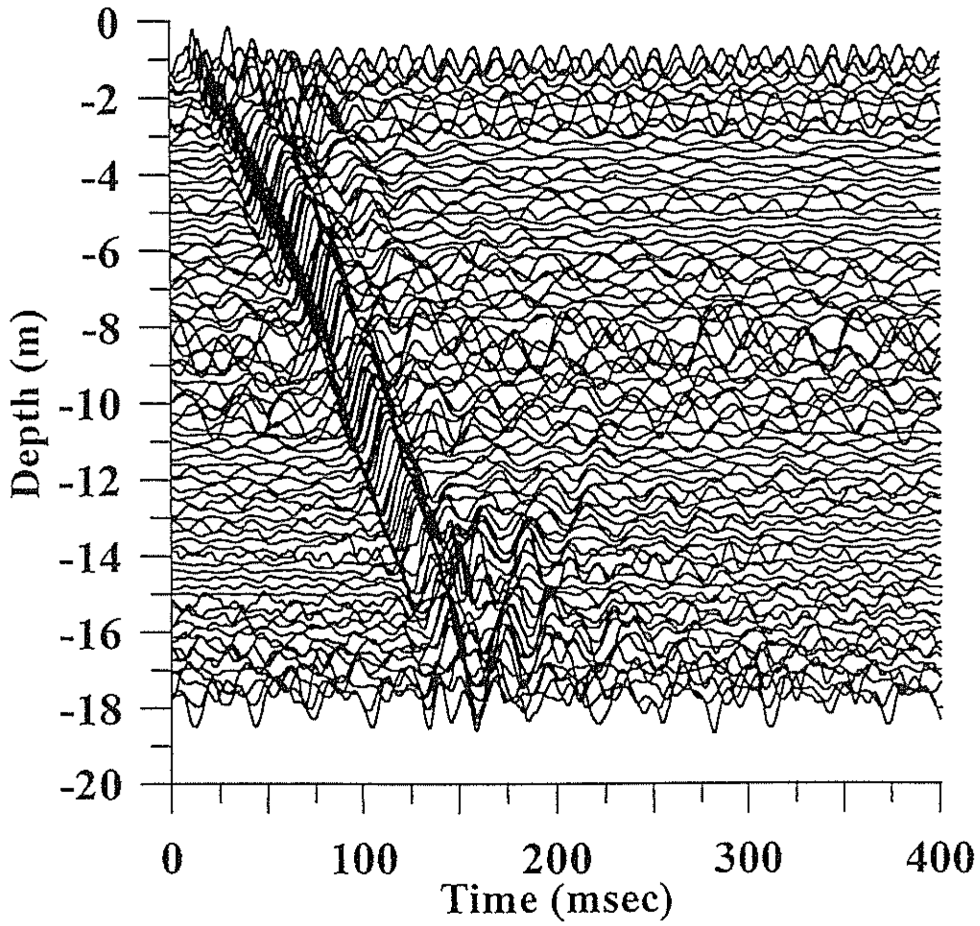

Fig. 24 Seismic CPT results - Ormond Road, Hastings

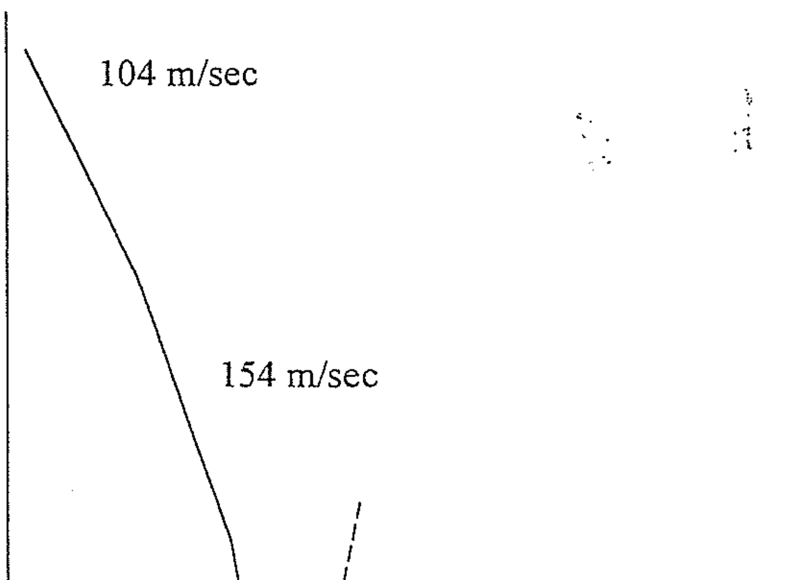

Fig. 25 Interpretation - Ormond Road, Hastings

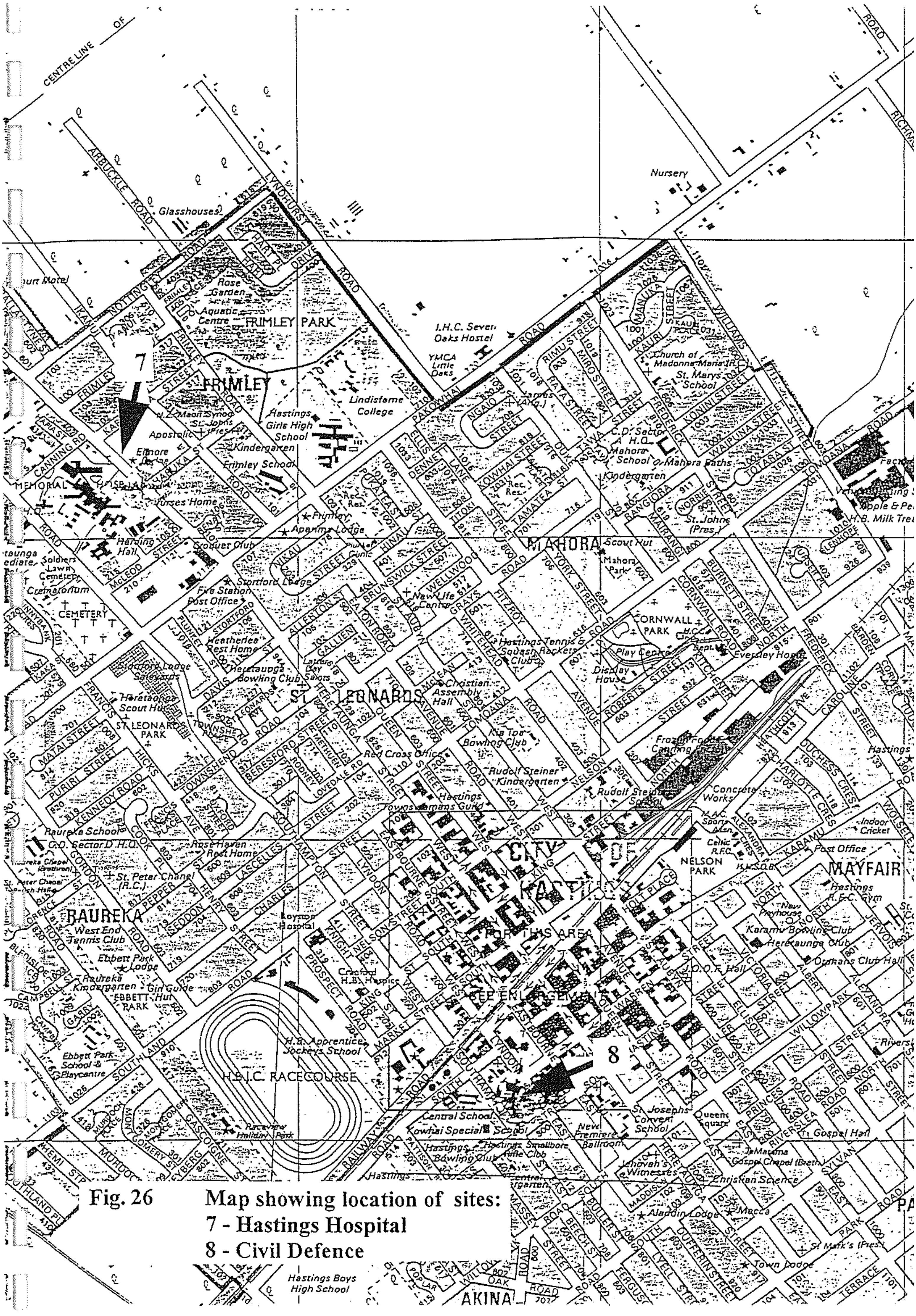

Fig. 26 Map showing location of sites:
7 - Hastings Hospital
8 - Civil Defence

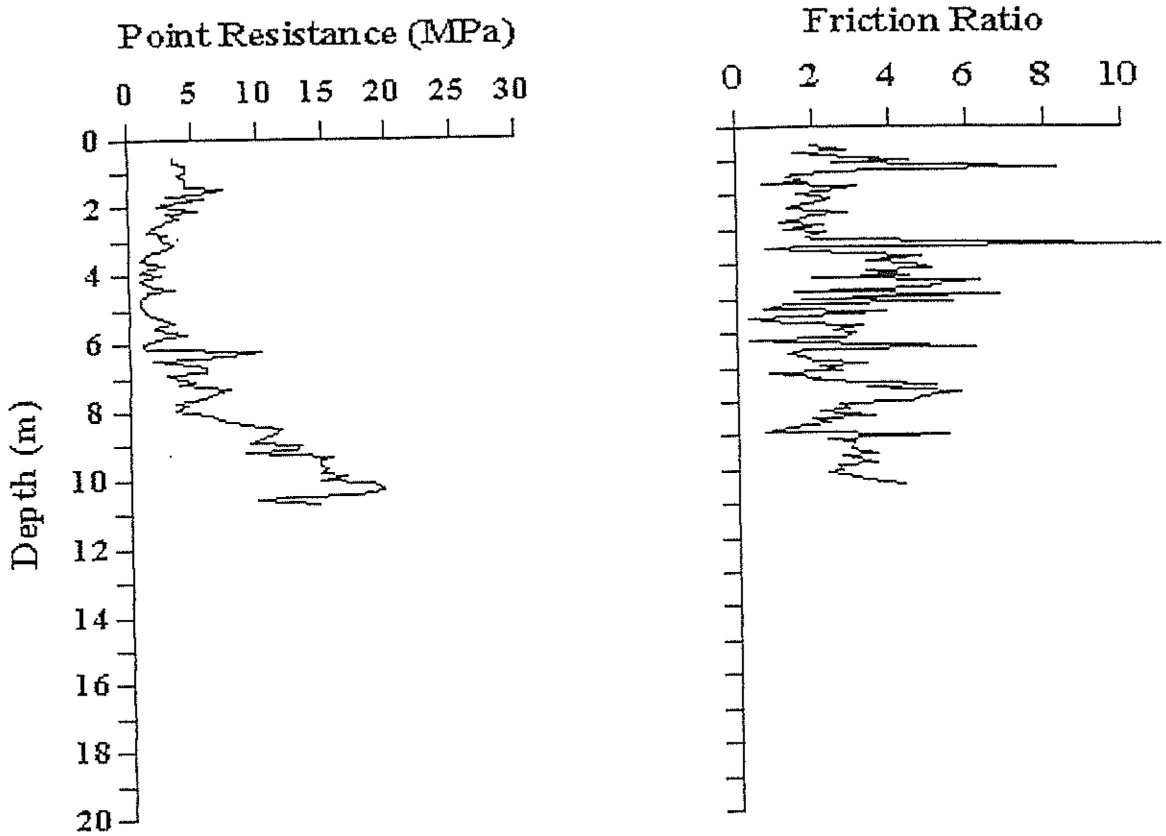

Fig. 27 CPT results - Hastings Hospital

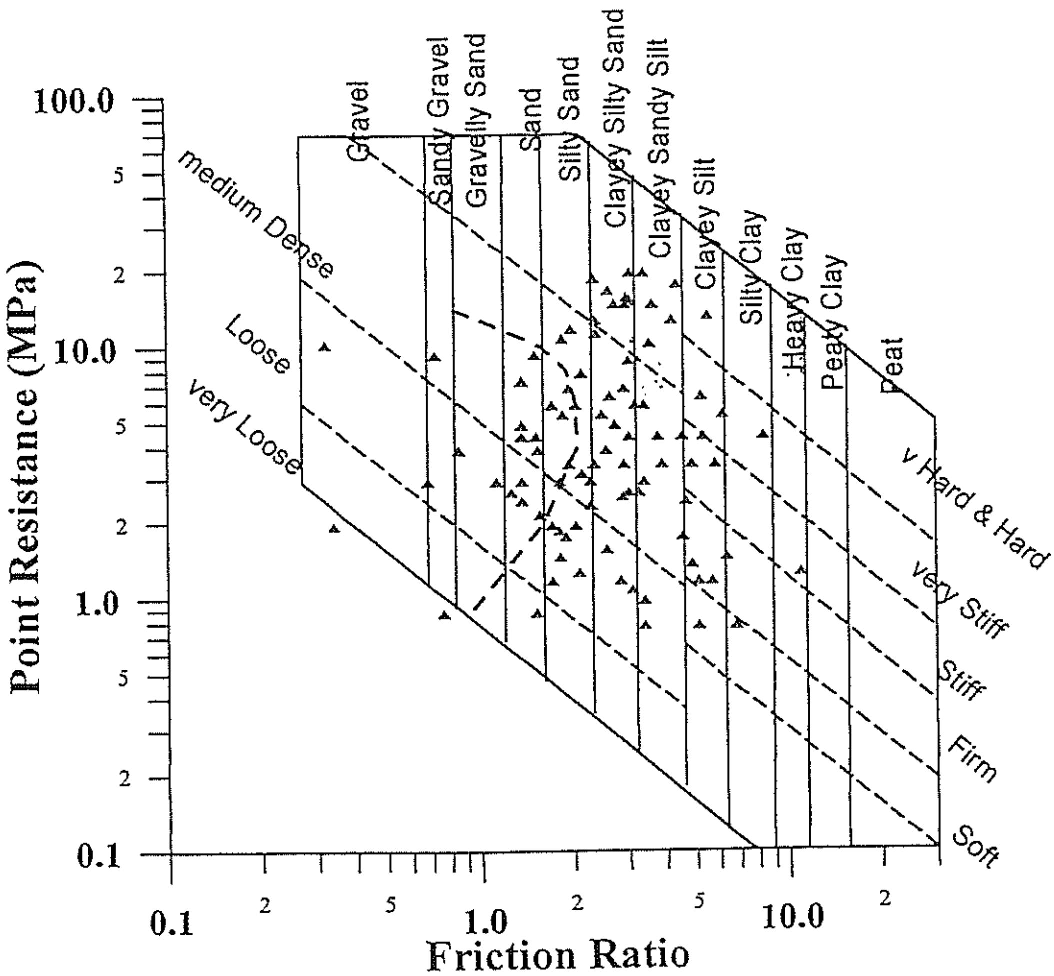

Fig. 28 Inferred texture & potential liquefaction - Hastings Hospital

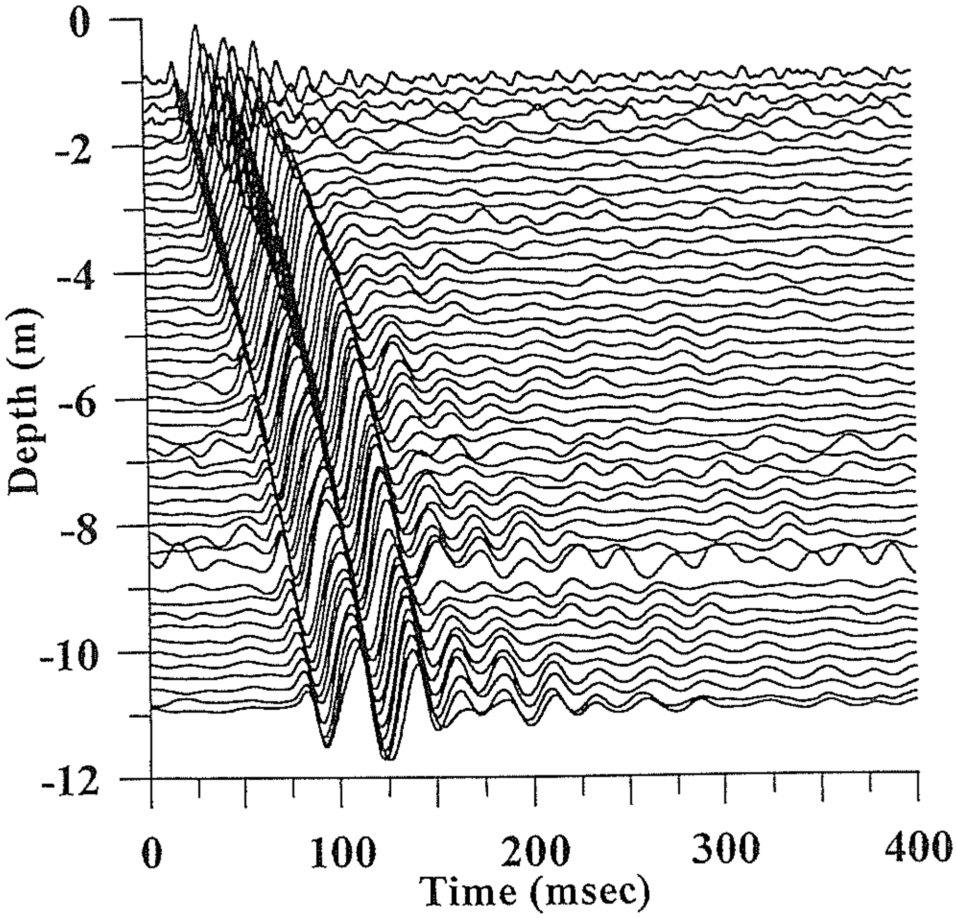

Fig. 29 Seismic CPT results - Hastings Hospital

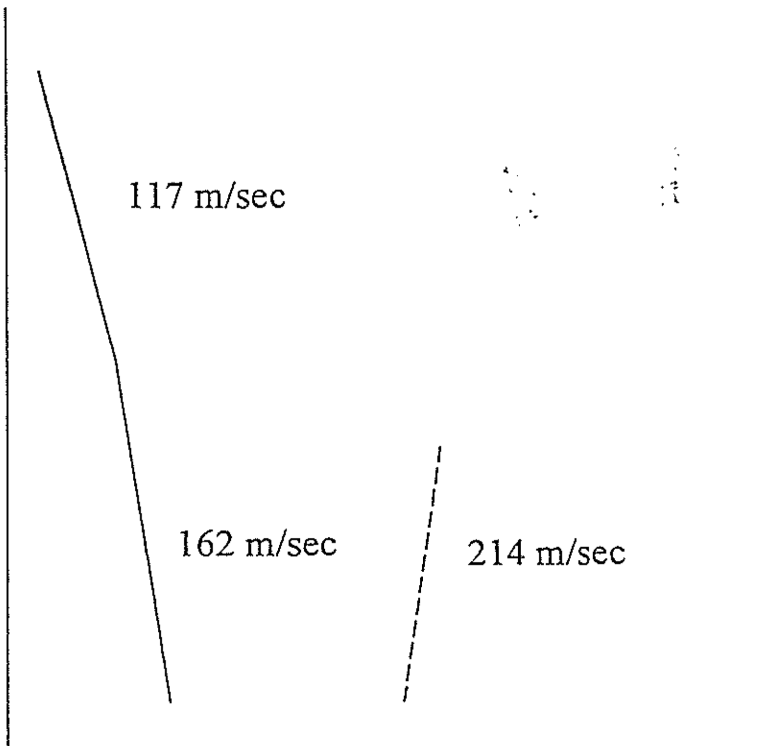

Fig. 30 Interpretation - Hastings Hospital

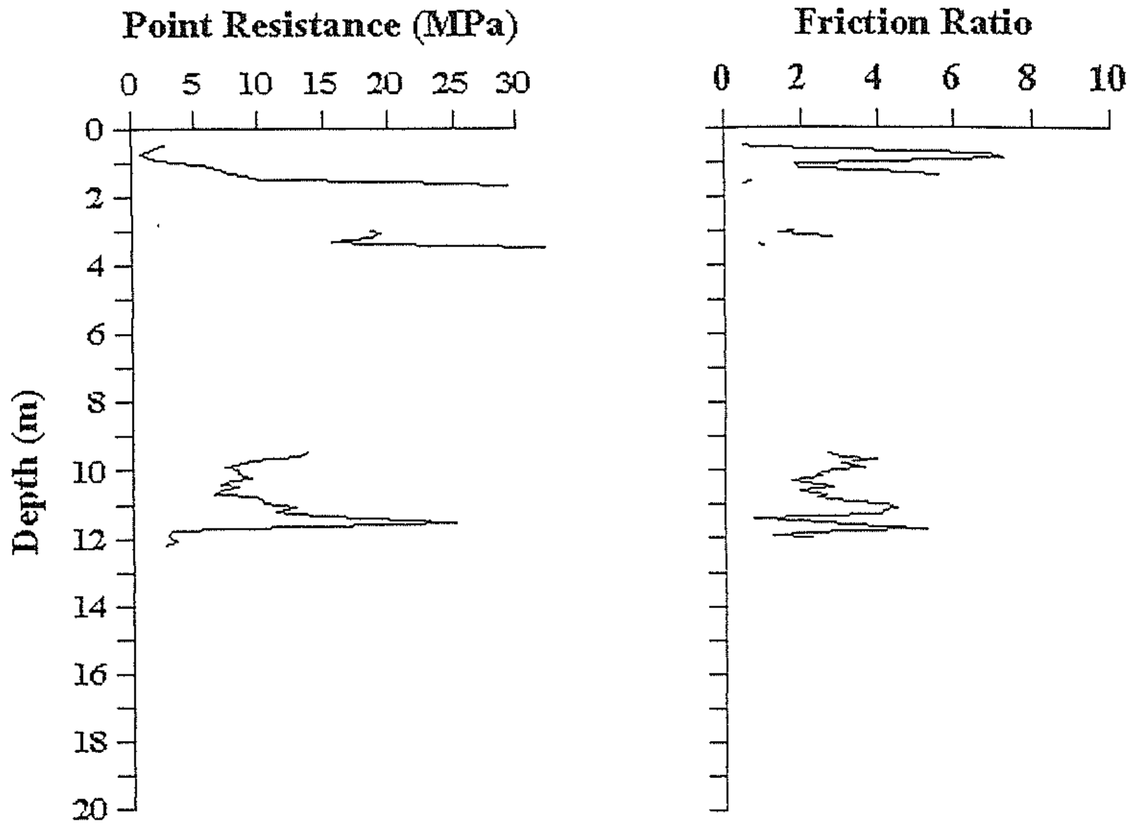

Fig. 31 CPT results - Civil Defence, Hastings

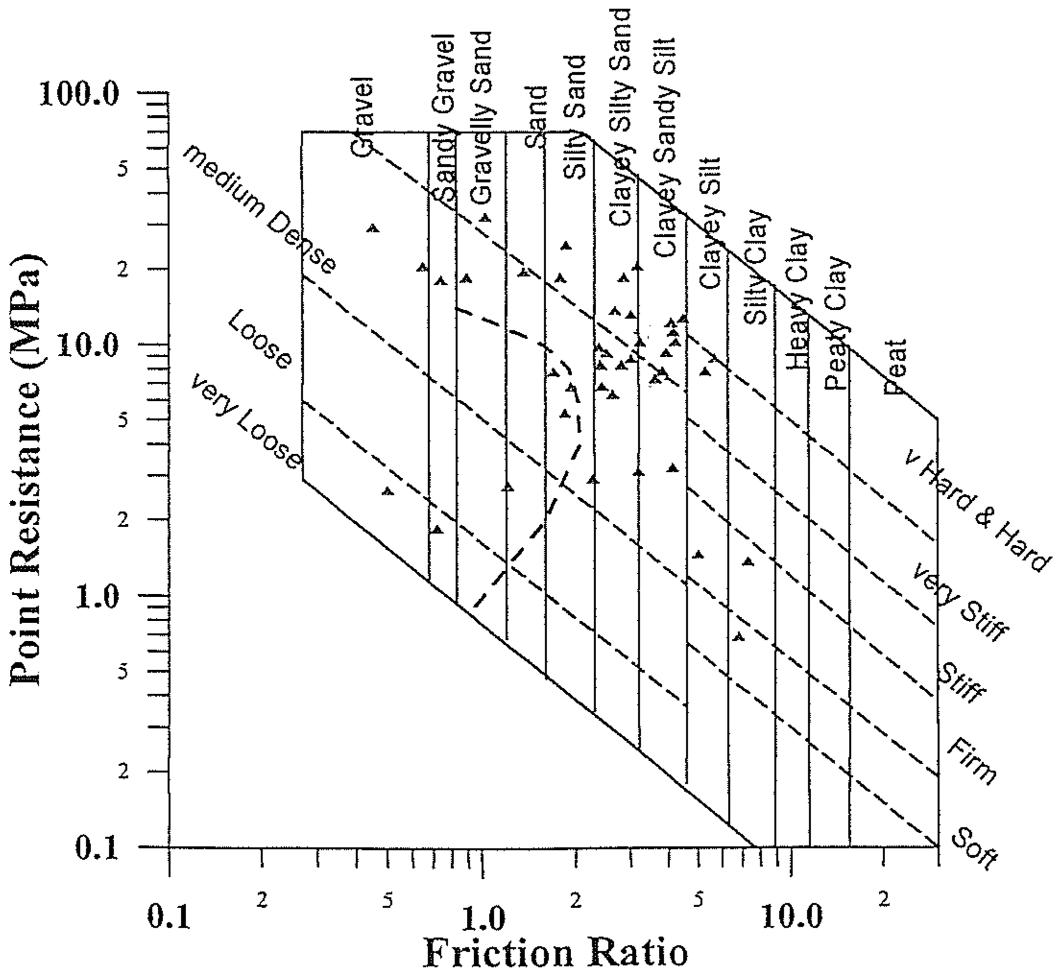

Fig. 32 Inferred texture & potential liquefaction - Civil Defence, Hastings

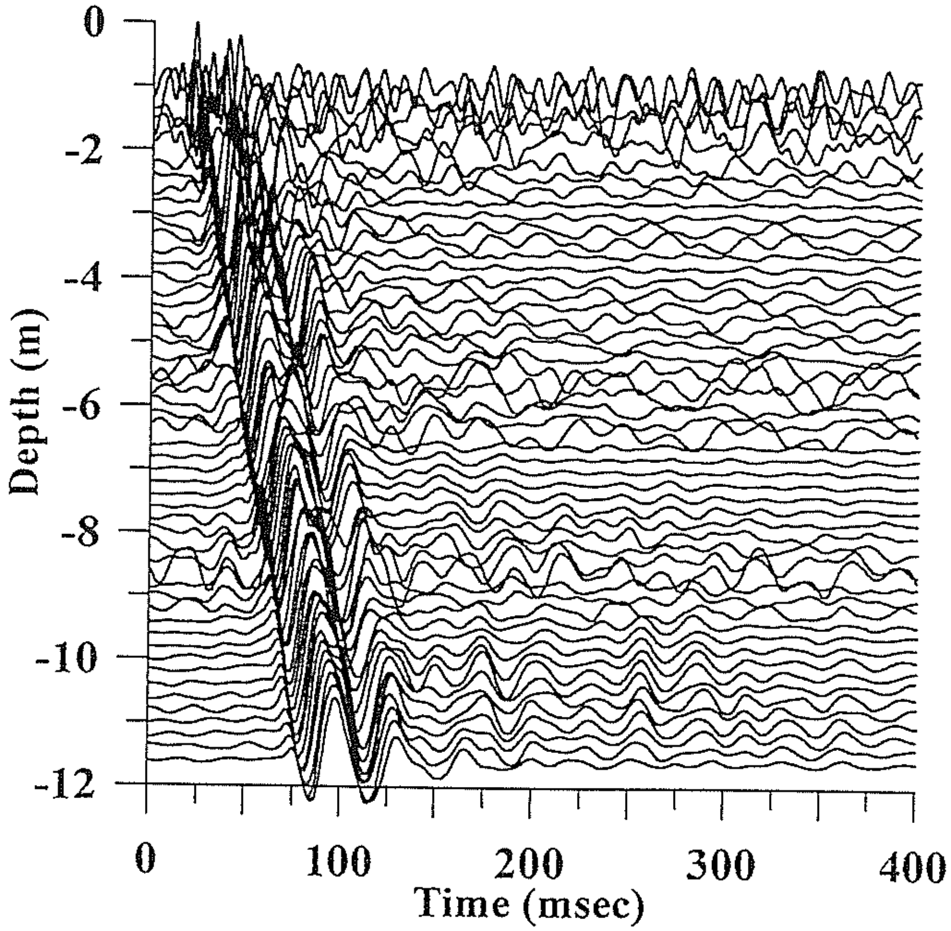

Fig. 33 Seismic CPT results - Civil Defence, Hastings

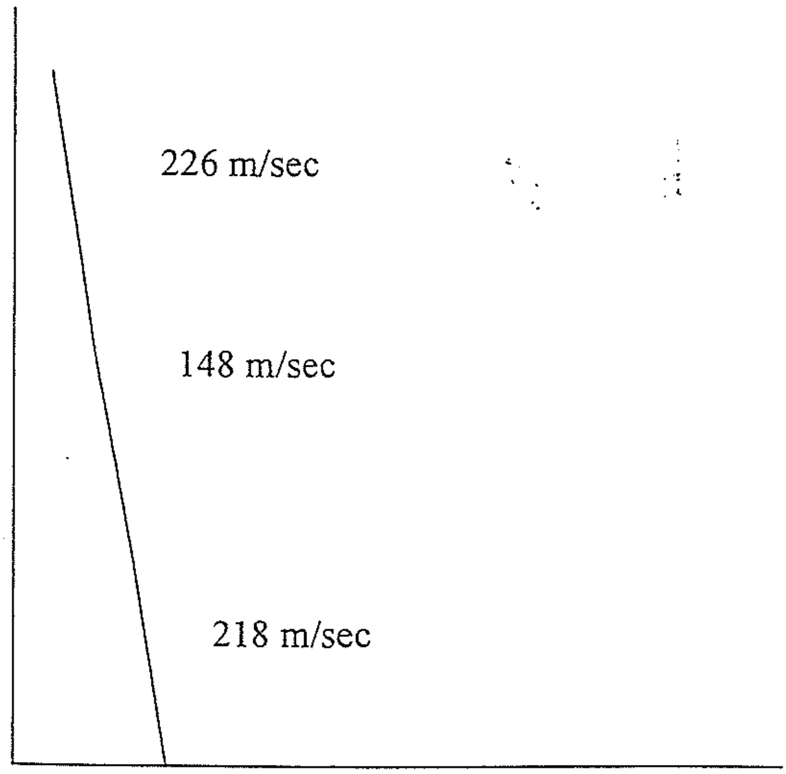

Fig. 34 Interpretation - Civil Defence, Hastings